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SUBSTITUTE CHEMICAL PROGRAM

INITIAL SCIENTIFIC AND MINIECONOMIC REVIEW OF MALATHION

MIDWEST RESEARCH INSTITUTE

PREPARED FOR

ENVIRONMENTAL PROTECTION AGENCY

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This is the third of a series of in-depth scientific literature searches which review the safety and efficacy of substitute chemicals registered by EPA as possible replacements for cancelled or suspended pesticides or pesticides in litigation. The reviews are part of the Substitute Chemical Program, initiated under PL 93-135 (October 1973). This report on Malathion, a pesticide substituting for some uses of DDT, reviews ~~Malathion's~~ the chemistry and analytical methods, its toxicity to laboratory and domestic animals and to humans, its effects on the environment, and its use patterns, costs and efficacy. The review is a compilation and summarization rather than an interpretation of published and unpublished scientific test and use data from various sources, including journals, books, Federal and State agency reports and manufacturer and university reports.

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animal consumption
U.S. Tolerances for malathion
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acute toxicity
subacute oral toxicity
chronic toxicity - rats
subacute dermal and inhalation toxicity - guinea pigs
respiratory exposure -workers
registered uses, dosage rates
tolerances, use limitations
boll weevils, other cotton pests
spider mites
sorghum greenbugs
sorghum midge
cherry fruit fly
tarnished plant bug
zooplankton
benthic invertebrates
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U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF PESTICIDE PROGRAMS
CRITERIA AND EVALUATION DIVISION
WASHINGTON, D.C. 20460

This report has been compiled by the Criteria and Evaluation Division, Office of Pesticide Programs, EPA, in conjunction with other sources listed in the Preface. Contents do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

PREFACE

The Alternative (Substitute) Chemicals Program was initiated under Public Law 93-135 of October 24, 1973, to "provide research and testing of substitute chemicals." The legislative intent is to prevent using substitutes, which in essence are more deleterious to man and his environment, than a problem pesticide (one that has been suspended, cancelled, deregistered or in an "internal review" for suspected "unreasonable adverse effects to man or his environment"). The major objective of the program is to determine the suitability of substitute chemicals which now or in the future may act as replacements for those uses (major and minor) of pesticides that have been cancelled, suspended, or are in litigation or under internal review for potential unreasonable adverse effects on man and his environment.

The substitute chemical is reviewed for suitability considering all applicable scientific factors such as: chemistry, toxicology, pharmacology and environmental fate and movement; and socio-economic factors such as: use patterns and costs and benefits. EPA recognizes the fact that even though a compound is registered it still may not be a practical substitute for a particular use or uses of a problem pesticide. The utilitarian value of the "substitute" must be evaluated by reviewing its biological and economic data. The reviews of substitute chemicals are carried out in two phases. Phase I conducts these reviews based on data bases readily accessible at the present time. An Initial Scientific Review and Minieconomic Review are conducted simultaneously to determine if there is enough data to make a judgment with respect to the "safety and efficacy" of the substitute chemical. Phase II is only performed if the Phase I reviews identify certain questions of safety or lack of benefits. The Phase II reviews conduct in-depth studies of these questions of safety and cost/benefits and consider both present and projected future uses of the substitute chemicals.

The report summarizes rather than interprets scientific data reviewed during the course of the studies. Data is not correlated from different sources. Opinions are not given on contradictory findings.

This report contains the Phase I Initial Scientific and Minieconomic Review of Malathion (S-[1,2-bis(ethoxycarbonyl)-ethyl]0, 0-dimethyl phosphordithioate). Malathion was identified as a registered substitute chemical for certain cancelled and suspended uses of DDT. Where applicable, the review also identifies areas where technical data may be lacking so that appropriate studies may be initiated to develop desirable information.

The review covers all uses of malathion and is intended to be adaptable to future needs. Should malathion be identified as a substitute for a problem pesticide other than DDT, the review can be updated and made readily available for use. The data contained in this report was not intended to be complete in all areas. Data searches ended in the Fall of 1974. The review was coordinated by a team of EPA scientists in the Criteria and Evaluation Division of the Office of Pesticide Programs. The responsibility of the team leader was to provide guidance and direction and technically review information retrieved during the course of the study. The following EPA scientists were members of the review team: George Bagley (Chemistry), team leader; Merry L. Alexander (Chemistry); Elsie Kelley (Pharmacology and Toxicology); Jacob W. Lehman (Fate and Significance in the Environment); E. David Thomas, Ph.D. (Registered Uses); Jeff Conopask (Economics).

Data research, abstracting and collection were primarily performed by Midwest Research Institute, Kansas City, Missouri (EPA Contract #68-01-2448). RvR Consultants, Shawnee Mission, Kansas, under a subcontract to Midwest Research, assisted in data collection. American Cyanamid Company, the manufacturer of malathion, made scientific recommendations and additions to this report. The recommendations of the following National Environmental Research Centers, EPA Office of Research and Development have also been incorporated: Gulf Breeze Environmental Research Laboratory, Gulf Breeze, Florida; National Water Quality Laboratory, Duluth, Minnesota; Southeast Environmental Research Laboratory, Athens, Georgia.

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PART I. SUMMARY

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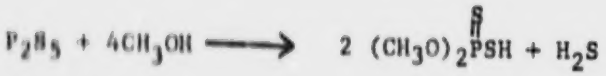
This section contains a summary of the "Initial Scientific and Minieconomic Review" conducted on malathion. The section summarizes rather than interprets scientific data reviewed.

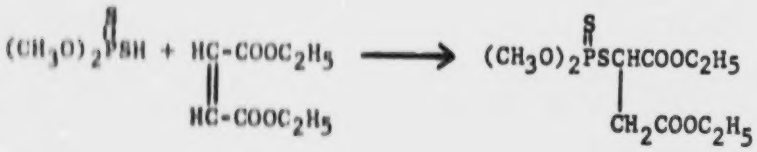
Production and Use

Malathion (S-[1,2-bis(ethoxycarbonyl)-ethyl]O,O-dimethyl phosphorodithioate) has a very broad spectrum of effectiveness against insects and mites. The estimated U.S. production of malathion in 1972 is 24 million pounds as active ingredient (AI). American Cyanamid Company, Warners, New Jersey, is the only domestic manufacturer of malathion.

Only two reactions are involved in the manufacture of malathion. In the first (1),O,O-dimethyl dithiophosphoric acid is made by reacting methanol and phosphorus pentasulfide. In the second reaction (2), the acid is reacted with diethyl maleate to produce malathion :



$$P_2S_5 + 4CH_3OH \longrightarrow 2\ (CH_3O)_2\overset{\overset{S}{\|}}{P}SH + H_2S \qquad (1)$$



$$(CH_3O)_2\overset{\overset{S}{\|}}{P}SH + \begin{array}{l} HC\text{-}COOC_2H_5 \\ \ \| \\ HC\text{-}COOC_2H_5 \end{array} \longrightarrow \begin{array}{l} (CH_3O)_2\overset{\overset{S}{\|}}{P}SCHCOOC_2H_5 \\ \qquad\qquad\ | \\ \qquad\qquad CH_2COOC_2H_5 \end{array} \qquad (2)$$

The chemistry of malathion has been the subject of extensive study. Hydrolysis, the most important decomposition reaction, has received the most intense investigation. Depending upon the reaction conditions, hydrolysis can occur via several different pathways leading to a variety of products. In aqueous systems, the rate of hydrolysis is pH dependent; "instantaneous" hydrolysis at pH 12; 50% hydrolysis in 12 hr at pH 9; and no hydrolysis detected after 12 days in slightly acid solution (pH 5 to 7). In neutral aqueous solutions 59.3% hydrolysis was reported after 1 week.

Malathion is readily oxidized to malaoxon by a number of mild oxidizing agents, and is also degraded by ultraviolet radiation. On prolonged contact with iron, malathion is reported to decompose and completely lose insecticidal activity.

Malathion is available for domestic use in a variety of different formulations in which it is the only active ingredient. These include emulsifiable liquids, wettable powders, dusts, solutions, and concentrates for low volume (LV) and ultra-low volume (ULV) applications. In addition, a number of liquid and dry formulations are available that contain malathion in combination with other insecticides and/or fungicides.

The most widely used formulations of malathion are the ULV concentrates containing 95% active ingredient (9.7 lb AI/gal), applied by ground or air equipment; and the 57% (5 lb AI/gal) emulsifiable liquid.

It is estimated that about 16.2 million pounds of malathion (as AI) were used in the United States in 1972. Consumption of malathion by category of use in 1972 is estimated to have been: agriculture - 5 million pounds; industrial and commercial uses - 4 million pounds; government agencies - 2.2 million pounds; and home and garden uses - 5 million pounds. Agricultural use of malathion in 1972, by region, is estimated to have been: Northeastern States - 0.2 million pounds; Southeastern States - 1.05 million pounds; North Central States - 1 million pounds; South Central States - 1.05 million pounds; Northwestern States - 0.7 million pounds; and Southwestern States - 1 million pounds.

Pharmacology and Toxicology

Toxicity

The largest dose of malathion that has been reported as nonfatal to humans is 200 mg/kg of body weight; the smallest fatal dose reported is 71 mg/kg of body weight. The threshold of incipient toxicity to humans appears to be 24 mg of malathion. The estimated acceptable daily intake for man is 0.02 mg/kg of body weight.

Rats have been fed on a diet that contained up to 5,000 ppm of malathion for 2 years without mortality, although body weight gain was reduced and blood cholinesterase levels were depressed. When the dosage was raised to 20,000 ppm, there were marked reductions of growth, food intake, and blood cholinesterase activity. A "no effect" level of 100 ppm has been established for malathion in rats.

Acute oral toxicity for a number of species is summarized as follows:

Acute Oral Toxicity of Malathion

Species	LD_{50} value (mg/kg)
Rat	1,000-1,845
Mouse	720-3,321
Guinea pigs	570-815
Chickens	
Adult	> 850
1 year old	150-200
3 to 4 weeks	200-400
2 to 3 weeks	370
Cats	> 500
Rabbits	> 900
Sheep	< 150
Cattle	200-560
Calves (dairy)	80

A summary of the toxicity of malathion via routes other than oral is given below:

Toxicity of Malathion Via Routes Other Than Oral

Species	Routes of entry	Measurement	Value	
			Male	Female
Rat	Intraperitoneal	LD_{50} (mg/kg)	750	1,000
	Intravenous	LD_{50} (mg/kg)	50	50
	Subcutaneous	LD_{50} (mg/kg)	1,000	--
	Dermal	LD_{50} (mg/kg)	> 4,444	> 4,444
	Inhalation	LC_{50} 8 hr (mg/ℓ)	> 60	> 60
Mice	Intraperitoneal	LD_{50} (mg/kg)	420 to 815	
	Inhalation	LC_{50} 8 hr (mg/m^3)	> 15	
Guinea pigs	Intraperitoneal	LD_{50} (mg/kg)	500 420 to 474	
	Dermal, 24-hr exposure	LD_{50} (mg/kg)	> 12,300	
	Inhalation, 5 ppm 4 weeks		No effect	
Dogs	Intraperitoneal	LD_{50} (mg/kg)	1.51 ml/kg*	
	Intravenous	LD_{50} (mg/kg)	> 430 to < 600	
	Inhalation, 5 ppm 4 weeks		Blood cholinesterase activity reduced	
Rabbits	Dermal	LD_{50} (mg/kg)	2,400 to 6,150	

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* Of a 95% malathion solution.

In summary, malathion has a low oral toxicity in all mammals except cattle and sheep. The reason for the apparent sensitivity of cattle and sheep was not determined. There does not appear to be a toxic differentiation due to sex, such as found with some other organophosphate pesticides.

Malathion has a low toxicity by all the routes that have been investigated with the exception of intravenous injection and inhalation. This observation leads to the question of the role of malathion entry to physiological systems.

Metabolism

Malathion is readily absorbed from the gastrointestinal tract by passive transport, but is only slowly absorbed through the skin. Very low concentrations of malathion are widely distributed in tissues. Concentrations in bone and liver are somewhat higher. There is no evidence of long-term accumulation of malathion (or malaoxon) in body tissues. Malathion metabolites are mostly excreted in urine. In mammals these urinary metabolites are mainly mono- and di-acids of malathion. The principal fecal metabolite is dimethyl phosphate. Malathion requires activation for anticholinesterase activity by conversion from the thiol to its oxygen analogue. Activation is at the microsomal level and requires $NADH_2$, Mg^{++}, and nicotinamide. Malathion is degraded by phosphatases and carboxylesterases or aliesterases. Malathion toxicity is potentiated by EPN, TOTP, and possibly some other organophosphates. Potentiation has been postulated to be mediated via carboxylesterase or aliesterase inhibition, but the mechanism is not fully understood. Some evidence indicates that potentiation may be via multiple mechanisms.

Reproduction

The hatchability of hen eggs injected with sufficient malathion dissolved in 0.02 ml acetone to yield 25, 100, 200, 300, 400, and 500 ppm malathion was reported to be 85%, 87%, 62%, 71%, 42%, and 6%, respectively. Eggs injected with sufficient malathion dissolved in 0.02 ml corn oil to yield concentrations of 50, 100, and 200 ppm showed hatchability of 84%, 9%, and 9%, respectively.

Malathion has been reported to have little, if any, effect on the metabolism and motility of boar spermatozoa.

Teratology

The effect of intraperitoneal injections of malathion on the rat fetus has been studied by injecting female rats with 600 and 900 mg/kg. The pregnant rats were given a single intraperitoneal injection of malathion on day 11 after insemination. No significant difference was found between the malathion-treated females and the controls for: the number of dead fetuses per litter; incidences of resorption; average weight of fetuses; average weight of placenta; or malformations of the fetuses.

An injection of 1 mg of malathion into 4-day old hen eggs has shown no detectable teratogenic signs, and the length of embryo parts indicated no difference between malathion injected eggs and controls. Furthermore, cholinesterase of the embryo was not decreased. Malathion injected into the egg as a level of 1 mg/egg reduced hatchability to 70% as compared to the controls at 95% hatchability, although there was no indication of parrot beak, or abnormalities of the legs or feathers.

The effect of malathion on the hard clam, *Mercenaria mercenaria*, and the American oyster, *Crassostrea virginica*, has also been investigated. The TL_m value for hatchability was determined to be 9.07 ppm; TL_m value for larvae survival was determined to be 2.66 ppm.

Mutagenesis

A review of the literature did not reveal any information on the mutagenic effects of malathion.

Oncogenesis

Data was not found concerning the oncogenic effects of malathion.

Food Tolerances and Acceptable Intake

Tolerances for malathion have been established in the United States on 127 raw agricultural commodities. The tolerances range from 0.1 to 8 ppm on food crops, and up to 135 ppm on forage crops. Malathion tolerances established by the World Health Organization range from 0.5 to 8 ppm (no ratings on forage crops).

The acceptable daily intake (ADI) for malathion was set at the 1966 joint meeting of the FAO Committee on Pesticides in Agriculture and the WHO Expert Committee on Pesticide Residues. The ADI for malathion is 0.02 mg/kg.

The results obtained from the analysis of domestic foods over a 4-year period by the FDA show the amount of malathion consumed to be well below the ADI. Malathion, however, apparently does account for the majority of the total organophosphates present in foods (0.00013 of the total 0.00017 mg/kg body weight/day).

Environmental Effects

Available data shows that malathion is highly toxic to fish and benthic invertebrates, and the potential for damage to these populations exists when malathion is used at insecticidally effective rates of application over or near aquatic environments. A brief summary of the toxicity of malathion to aquatic species is as follows:

TL_m for Malathion for Fish

	Hour	ppm		Hour	ppm
Black bullhead	96	12.9	Green sunfish	48	0.70*
Bluegill	48	0.12	Guppy	48	0.88
Carp	48	10.0	Labeo fimbreatus	48	8.5
Cirrhina mrigala	48	7	Labeo rohita	48	8.0
Danio sp.	48	13.5	Largemouth bass	48	0.28*
Fathead minnow	48	24.0	Rainbow trout	96	0.170
Goldfish	96	10.7	Tilapia	48	5-8.3

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* Twenty percent emulsifiable concentrate.

LC_{50} of Malathion for Benthic Invertebrates (ppb)

Species	Temperature (°F)	Time (hr)	Value
Stoneflies			
Pteronarcys californica	60	24	35
	60	48	20
Acroneuria pacifica	52-53	48	12
Pteronarcella badia	60	24	10
	60	48	60
Claassenia sabulosa	60	24	13
	60	48	6
Caddisflies			
Arctopsyche grandis	51-54	96	32
Hydropsyche californica	51-54	96	22.5
Mayflies			
Ephemerella grandis	48-50	96	100
Baetis sp.	70	48	6
Amphipods			
Gammarus lacustris	70	24	3.8
	70	48	1.8

Reports on fish toxicity of malathion degradation products are somewhat contradictory. In view of the large-scale use of malathion (including use over and near aquatic environments); it is apparent that more information on the identification, toxicity, persistence, and fate of these degradation products in the aquatic environment is needed.

Most species of wildlife exposed to malathion applications at dosage rates required for insect control apparently tolerate the insecticide rather well. Effects on wildlife outside of target areas appear to be minimal. Mice and quail exposed to ground applications of ULV malathion at one and 10 times the recommended rate (1.5 and 15.0 fluid oz/min) did not exhibit any poisoning symptoms. Caged quail exposed to malathion spray (12 to 16 fluid oz/acre) in the field and fed on sprayed feed showed small differences in growth rates compared to untreated birds.

The subacute oral toxicity of malathion to avian species is as follows:

Species	5-Day LC_{50} (ppm)
Bobwhite quail	3,497
Japanese quail	2,128
Mallard duck	> 5,000
Ring-necked pheasant	4,320

Available data indicates that in most crop-pest-predator/parasite systems, malathion appears to have little, if any, selective toxicity to pest species. In some instances, malathion appears to be more toxic to beneficial than to pest insects. Malathion is highly toxic to many beneficial parasites and predators, including lady beetles (Hippodamia convergens), adult Orius insidiosus, the parasitic wasps Apanteles marginiventris and Campoletis perdistinctus, and green lacewing larvae (Chrysopa spp.).

Malathion has been shown to be one of the most toxic pesticides to bees. The residual action on bees of ULV application of malathion was over four times greater than that usually encountered following dilute malathion applications.

The scientific data on the residues and fate of malathion show that malathion is rapidly degraded in the soil. Disagreement exists, however, on the relative contributions of chemical versus microbiological processes to this degradation. All data reviewed indicates that malathion residues in the soil are very short-lived. Degradation in the soil is reported to be 50 to 90% in 24 hr, depending on the soil type.

The data reviewed indicates that a number of soil microorganisms are capable of degrading malathion. However, reports were not found regarding to what extent, if any, such processes may occur under field conditions. Malathion does not appear to inhibit terrestrial microorganisms at concentrations likely to result from insecticidal use.

Residues of malathion in natural waters are apparently degraded rather rapidly. Concentrations of 0.5 ppm malathion in field water samples were found to degrade with a half-life ranging from 0.5 to 10 days, depending primarily upon pH. In river water, 25% of the original concentration of malathion remained after 1 week, 10% after 2 weeks, and no detectable concentration after 4 weeks. Under the same test conditions, malathion remained stable in distilled water for 3 weeks. The half-life of malathion in water is reported to be about 1 month at pH 8 and 28°C; the range for half-life of malathion is several days to months, depending on pH, temperature, and other environmental conditions.

It has been reported that malathion can form relatively persistent and possibly toxic degradation products in water. Laboratory tests showed that malathion breaks down in water by competing pathways, one of which yields compounds that are considered nontoxic to aquatic organisms. The other pathway, which is favored in colder water (35°F), results in the formation of malathion acids which may possess some of the toxic properties of malathion and appear to be more persistent in the environment than the parent compound.

The effect of water on the adsorption of malathion onto five montmorillonite systems has been studied. Malathion penetration of the interlayer regions of montmorillonite was very slow below 30% relative humidity. At relative humidities exceeding 40%, malathion penetrated within minutes and was adsorbed as a double layer. The mechanisms of adsorption was through a hydrogen bonding interaction between the carbonyl oxygen atoms and the hydration water shells of the saturating cations. Changes in the hydration status of the clay system produced marked reversible alterations in the spectrum of adsorbed malathion that were believed due to orientation and interaction effects. No degradation of adsorbed malathion was observed.

The available data indicates that, under field conditions, malathion is degraded by chemical as well as by biological mechanisms. The data, for the most part, indicates that chemical degradation is more important under field conditions. The data also indicates that volatilization does not appear to be a major transport mechanism by which malathion may move away from target sites after application.

Malathion has been rated using an index designed to determine the propensity of pesticides for volatilization and leaching under simulated field conditions for loam soils at 25°C and an annual rainfall of 59 in. By this method, malathion rated a volatilization index of 2, indicating an estimated median vapor loss from treated areas of 1.8 lb/acre/year. This index number indicates that the propensity for volatilization of malathion from treated fields is in the intermediate range, compared to many other pesticides. Malathion rated a leaching index number of 2 to 3, indicating movement of 6 to 10 in. through the soil.

No data was found on the metabolism or the residues of malathion in or on nontarget higher plants.

There was also no data found dealing directly with the possible bioaccumulation or biomagnification of malathion.

Specific Hazards of Use

The data compiled during the subject review has not shown any of the specific uses of malathion to be substantial hazards to man and the environment. This lack of substantiation is significant in light of the extensive use and scientific investigation of malathion.

Limitations in Available Scientific Data

The review of scientific literature was based on available sources, given limitations of time and resources. Data was not found in a number pertinent areas: 1) the route and rate of metabolism of malathion in the environment; 2) the nature, persistence and toxicity of major degradation products of malathion to fish and other nontarget organisms.

Efficacy and Cost Effectiveness

The economic benefits of using malathion have been determined from 1972 cost data and from the results of field tests evaluating uses for controlling the boll weevil on cotton, the sorghum midge and greenbug on sorghum, the potato leafhopper on soybeans and potatoes, the sugar beet maggot on sugar beets, the corn rootworm on corn, the alfalfa weevil on alfalfa, the tarnished plant bug on strawberries, the Mexican bean beetle on beans, aphids on peas and potatoes, and the hornfly and other insect pests on cattle. However, the data is incomplete and should be looked upon with caution.

Malathion provides effective control for the boll weevil and two-spotted spider mites on cotton. However, it is not highly toxic to the tobacco budworm or bollworm and is not recommended by many states for control of these pests on cotton. Malathion is often used with methyl parathion to control all of these pests. Economic benefits from the use of malathion ranged from $6.70 to $700.20/acre when compared to untreated test plots.

Over 90% seasonal control of the greenbug on sorghum plants can be achieved with malathion. Excellent control of the sorghum midge has also been proven. However, the latter pest is not a major factor due to early uniform planting of sorghum plants. Economic benefits based on experimental tests of greenbug control comparing malathion treated plots to untreated plots ranged from $4.30 to $32.10/acre in the control of the greenbug.

Damage from the potato leafhopper on soybeans has lead to yield declines averaging 25.7 bushels/acre. Malathion at 1.0 lb/acre was used by Iowa farmers to control this pest and resulted in an economic benefit of $88.50/acre.

One test of malathion, applied to sugar beets for control of the sugar beet maggot, resulted in a 13% yield increase, equal to an economic benefit of $51.00/acre.

Malathion has shown mixed results for control of the alfalfa weevil. One author concluded that it was effective in warm weather but performed poorly in wet and cool weather. Economic benefits ranged from no increase to an increase of $54.40/acre.

Use of malathion for controlling grasshoppers on rangeland averaged 82 to 95%, resulting in an economic benefit of $5.40/acre.

Infestation rates from the cherry fruit fly in malathion-treated cherry fields in Oregon ranged between 0 and 0.57%. Untreated fields showed infestation rates as high as 10.06%. Yield data were unavailable from this test.

An application of 1.0 lb/acre of malathion 14 days after application of dimethoate has been shown to be an effective control for the tarnished plant bug on strawberries. Economic benefits ranges from $156.60 to $805.20/acre as the result of yield increases from the use of malathion.

Malathion effectively controlled the mexican bean beetles and yielded an economic benefit of $443.50/acre when applied to snap beans.

Malathion has been shown to give effective control of the hornfly on cattle. Weekly applications during the hornfly season have resulted in weight gains of 30 to 70 lb/animal. This use of malathion produces economic benefits ranging from $6.40 to $22.00/head.

Non-agricultural uses are significant in terms of volume (66%) although benefit estimation is very difficult because of the more abstract nature of aesthetic recreational and health benefits. The cost effectiveness of the latter can be determined.

PART II. INITIAL SCIENTIFIC REVIEW

SUBPART A. CHEMISTRY

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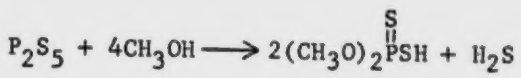
This section of the scientific review of malathion (S-[1,2-bis(ethoxycarbonyl)ethyl]0,0-dimethyl phosphorodithioate) contains a detailed review of available data on its chemistry and presence in foods. Seven subject areas have been examined: synthesis and production technology; physical properties of malathion; composition and formulation; chemical properties, reactions and decomposition processes; occurrence of residues in food and feed commodities; acceptable daily intake; and tolerances. The section summarizes rather than interprets scientific data reviewed.

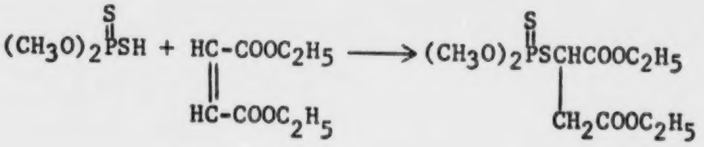
Synthesis and Production Technology

Malathion is manufactured by only one company in the United States, American Cyanamid, in Warners, New Jersey. Figure 1 is a production and waste schematic for malathion manufacture; Table 1 lists raw materials, and their sources and by-products, and wastes and their disposition as described by the company in 1971.

Only two reaction steps are involved in the manufacture of malathion. In the first reaction (1), 0,0-dimethyl dithiophosphoric acid (DMTA) is made by reacting methanol and phosphorus pentasulfide. In the second reaction (2), the acid is reacted with diethyl maleate (DEM) and/or diethyl fumarate (DEF) to produce malathion.



$$P_2S_5 + 4CH_3OH \longrightarrow 2(CH_3O)_2\overset{S}{\overset{\|}{P}}SH + H_2S \qquad (1)$$



$$(CH_3O)_2\overset{S}{\overset{\|}{P}}SH + \begin{matrix}HC\text{-}COOC_2H_5\\ \|\\ HC\text{-}COOC_2H_5\end{matrix} \longrightarrow (CH_3O)_2\overset{S}{\overset{\|}{P}}S\underset{CH_2COOC_2H_5}{\underset{|}{C}}HCOOC_2H_5 \qquad (2)$$

Suitable conditions for manufacture are specified in several U.S. patents. In one patent, Cassaday (1951)[1] uses an aliphatic tertiary amine catalyst, such as triethylamine, in the first reaction. The amount of amine is usually in the range from 0.2 to 2.0% of total weight of reactants. Cassaday also suggests use of an antipolymerization agent such as hydroquinone to guard against polymerization of the maleate or fumarate compound.

---

[1] Cassaday, J. T. (to American Cyanamid Company), U.S. Patent No. 2,278,652 (18 December 1951).

Table 1. RAW MATERIALS AND BY-PRODUCTS IN THE MANUFACTURE OF MALATHION

Raw materials

Material	Received from	Received by	Storage
1. P_2S_5	Three local sources	Truck, in tote bins	Tote bins
2. CH_3OH		Rail, tank cars	Bulk
3. Diethyl maleate	Linden, New Jersey	Pipeline	Bulk
4. Toluene	Local	Tank truck	Bulk
5. Caustic		Tank truck	Bulk

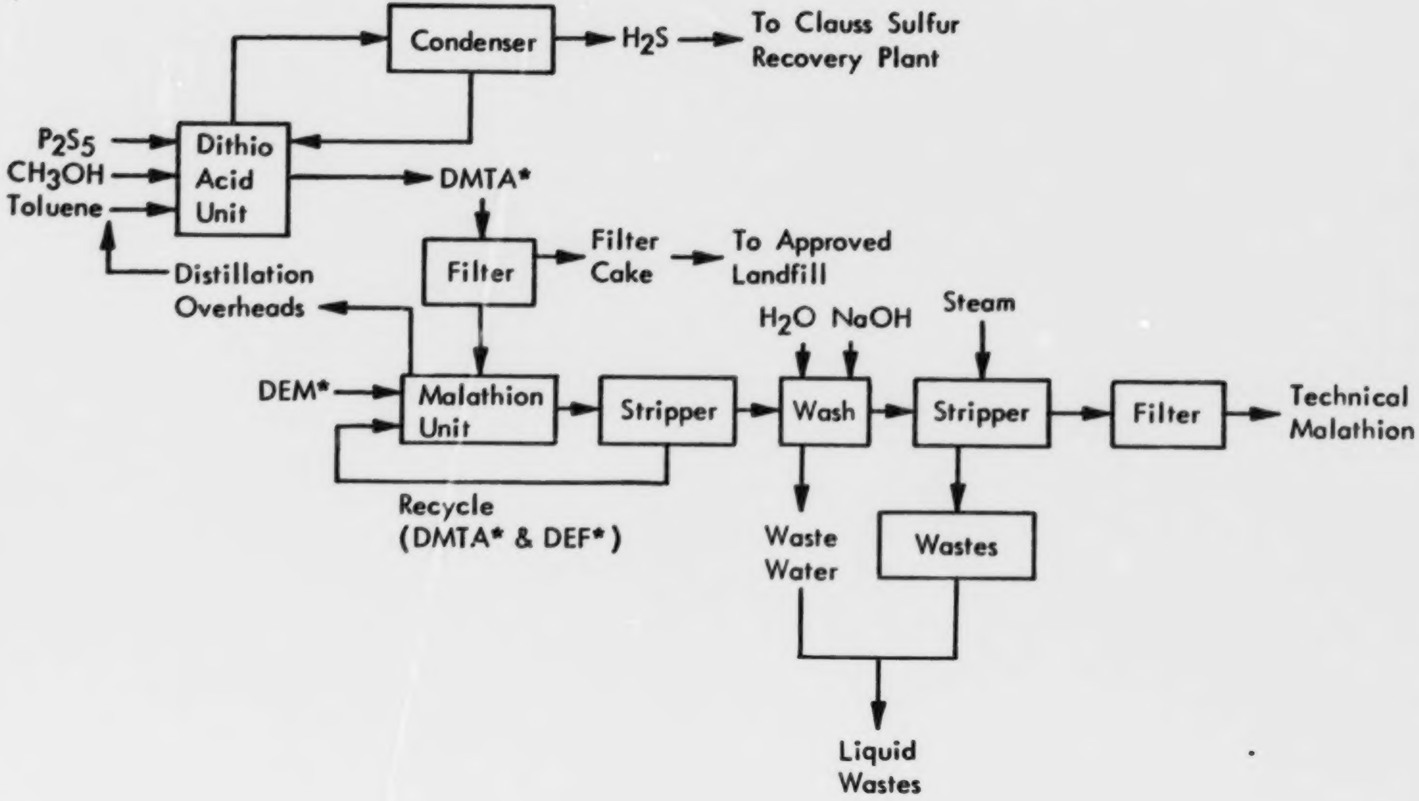
Reaction by-products

Material	Form	Amount produced (lb/lb AI)	Disposition
1. H_2S	Gas	0.052	Recovered as sulfur in new plant with good

Other process wastes and losses

Material	Form	Amount produced (lb/lb AI)	Disposition
1. Active ingredient	Aqueous	Unknown	Barge to deep sea
2. Solvents toluene	Liquid and some vapor	Unknown	Liquid barged to sea; vapor flared
3. Liquid wastes and spills			To holding pond eventually barged to the sea

Source: Lawless, E. W., and T. L. Ferguson (Midwest Research Institute), R. von Rumker (RvR Consultants), The Pollution Potential in Pesticide Manufacturing, for the Environmental Protection Agency, Contract No. 68-01-0142 (January 1972).


Condenser
H_2S
To Clauss Sulfur Recovery Plant
P_2S_5
CH_3OH
Toluene
Dithio Acid Unit
DMTA*
Distillation Overheads
Filter
Filter Cake
To Approved Landfill
DEM*
Malathion Unit
Stripper
Recycle (DMTA* & DEF*)
H_2O
NaOH
Wash
Steam
Stripper
Filter
Technical Malathion
Waste Water
Wastes
Liquid Wastes

* DMTA = O, O-dimethyl dithiophosphoric Acid, DEM = Diethyl Maleate, DEF = Diethyl Fumarate.

Source: Lawless et al., op. cit. (1972).

Figure 1. Production and waste schematic for malathion.

A fairly recent patent by Backlund et al. (1969)[1] describes the currently used method, which was developed to reduce the amount of diethyl fumarate in the final technical grade material. Diethyl fumarate has been found to cause skin sensitization or irritation to some people. This new process reduces the amount of diethyl fumarate from the 1 to 4% range to less than 0.5%, and it also increases production yields. The process is described as follows:

"There is initially reacted phosphorus pentasulfide and the methanol in the presence of a suitable solvent, such as dioxane, benzene, or toluene, at an elevated temperature, typically between about 170 and 190°F, and preferably between 175 and 185°F, to prepare O,O-dimethyl dithiophosphoric acid. The reaction mixture is next reacted with diethyl maleate, usually in a mole ratio of from about 1.02 to 1.15, and preferably from 1.02 to 1.10 moles of O,O-dimethyl dithiophosphoric acid to 1.0 mole of diethyl maleate. The reaction is terminated when the desired reaction product, namely, crude malathion, contains approximately between 10 and 25% of unconverted reactants. This terminal point is readily determined by intermittently analyzing the condensation or reaction mixture. Condensation reaction temperature is maintained from about 175 to about 225°F and preferably between about 190 to about 200°F. During the initial reaction period, pressure is reduced from about 760 mm Hg to between about 20 mm Hg and 30 mm Hg. The residence time for effecting partial or incomplete reaction is approximately 3 hr, during which time essentially all of the solvent is stripped off and recovered.

"Crude malathion reaction mixture containing between 10 and 25% of unconverted reactants is further subjected to heating at between about 250 and about 360°F, and preferably from 280 to about 320°F, and a reduced pressure of about 1 mm Hg to about 30 mm Hg in a low retention time-evaporation still, such as a wiped-film or falling film evaporator. This step is singularly critical so that most of the unconverted reactants and a small amount of malathion can be stripped off or removed from the mixture while avoiding the conversion to degradation products. The stripped overheads from the evaporator, which contain the unconverted reactants and some malathion, are then recycled to the reaction vessel for make-up with additional diethyl maleate and O,O-dimethyl dithiophosphoric acid. Thereafter, the bottoms containing desired malathion are washed with an aqueous sodium carbonate solution to eliminate residual acidic impurities, water washed and, finally, steam-stripped to yield dry malathion having minimum purity of about 97% and containing less than 0.5% of diethyl fumarate.

---

[1] Backlund, G. R., J. F. Martino, and R. D. Divine (to American Cyanamid Company), U.S. Patent No. 3,463,841 (25 August 1969).

"Malathion containing less than 0.5% of diethyl fumarate can, if desired, be readily prepared from the above-recovered steam-stripped product. The latter may be treated with an aqueous solution containing sodium sulfide, sodium sulfite, potassium sulfide, potassium sulfite, ammonium sulfide or ammonium sulfite to establish a pH of at least 7, and preferably between 7.1 and 7.5. The organic phase containing malathion of less than 0.1% diethyl fumarate content is then separated from the aqueous layer."

This patent (Backlund et al., 1969) also states that yields of malathion are 94%, based on diethyl fumarate, and 83%, based on phosphorus pentasulfide.

Physical Properties of Malathion

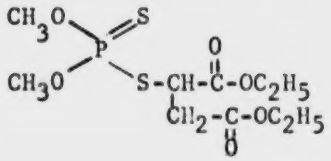
Chemical Name: S-[1,2-bis(ethoxycarbonyl)ethyl]O,O-dimethyl phosphorodithioate)

Common Name: Malathion

Trade Names: Cythion, Emmatos, Emmatos Extra, Fyfanon, Karbofos, Kop-Thion, Kypfos, Malaspray, Malamar, MLT, Zithio, Mercaptothion, Carbofos, Maldison

Pesticide Class: Nonsystemic insecticide and acaricide; organophosphate

Structural Formula:



Empirical Formula: $C_{10}H_{19}O_6PS_2$

Molecular Weight: 330.36

Analysis: C 36.35%; H 5.80%; P 9.38%; S 19.41%; O 29.06%

Physical State: Clear liquid, may be colorless, yellow, amber or brown

Characteristics: Technical grade material is a minimum 95% purity. It has a slight characteristic mercaptan-like odor resulting from as much as 30 ppm impurity as methyl mercaptan. Malathion insecticide concentrates may gel if stored in contact with iron, terneplate, or tin plate for a prolonged period. No gelation has been observed in finished malathion insecticide aerosols or other formulations containing 5% or less of the insecticide. Malathion insecticide concentrates may solidify if stored at temperatures near 32°F. Normal viscosity can be restored by allowing drums of malathion to warm up to 40°F. (Cyanamid International[1]).

Melting Point: 2.85°C

Boiling Point: 156 to 157°C at 0.7 mm Hg (slight decomposition)

Vapor Pressure: 0.00004 mm Hg at 30°C

Specific Gravity: 1.2315 at 25°C

Density: 10.25 lb/gal (1.2 kg/liter)

Refractive Index: n_D^{25} 1.4985

Viscosity: At 40°C, 17.57 centipoises (0.176 dyne/sec/cm^2)
At 25°C, 36.78 centipoises (0.368 dyne/sec/cm^2)

Flash Point (Tag Open Cup): Greater than 320°F (160°C)

Solubility: In water at 25°C, approximately 145 ppm. Completely soluble in most alcohols, esters, high aromatic solvents, ketones and vegetable oils. Poor solubility in aliphatic hydrocarbons.

---

[1] Cyanamid International, Malathion Insecticide for Adult Mosquito Control (Bulletin), Wayne, New Jersey.

Analytical Methods

This subsection reviews malathion analytical methods and the most significant of many primary information sources on the methods. The following information sources are described: (1) the Pesticide Analytical Manual (PAM), vols. I, II[1], (2) Official Methods of Analysis of the Association of Official Analytical Chemists[2], (3) Analytical Methods for Pesticides and Plant Growth Regulators[3].

The Pesticide Analytical Manual - The Pesticide Analytical Manual (PAM) published by the Food and Drug Administration, provides procedures and methods used by the FDA laboratories to examine food samples for the presence of pesticide residues. The PAM is published in two volumes. Volume I contains procedures for multi-residue methods (for samples of unknown history which may contain more than one pesticide). Volume II contains analytical methods used for specific pesticide residues and for specific foods.

Official Methods of Analysis of the Association of Official Analytical Chemists - The Association of Official Analytical Chemists (AOAC) publishes an authoritative methods manual about every 5 years. The manual is designed to provide both research and regulatory chemists with reliable methods of analysis. The reliability of the methods must be demonstrated by a published study showing the reproducibility of the method by professional analysts.

When an AOAC method is adopted for the first time it is published as "Official First Action." This designation serves notice that final adoption is pending, and permits an opportunity for any further study that may be deemed appropriate.

Methods that have performed successfully for at least 1 year are raised to the status of "Official Final Action."

A few methods are adopted as "Procedures." Such methods are generally sorting or screening methods or well-established types of examinations, or auxiliary operations, such as sampling or preparation of a sample, which may not have been subjected to collaborative study.

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[1] U.S. Department of Health Education, and Welfare, Food and Drug Administration, Pesticide Analytical Manual. 2 vols. (1971).

[2] Association of Official Analytical Chemists, Official Methods of Analysis of the Association of Official Analytical Chemists, 11th ed., Washington, D.C. (1970).

[3] Zweig, G., and J. Sherma, Analytical Methods for Pesticides and Plant Growth Regulators, Vol. VI: Gas Chromatographic Analysis, Academic Press, New York (1972).

Analytical Methods for Pesticides and Plant Growth Regulators, Volume VI, Gas Chromatographic Analysis - Chapter 6 of this text consists of an extensive and detailed review of specific and multi-residue analytical methods for organophosphate pesticides. This reference provides important information not available in AOAC's "Methods of Analysis" or the PAM such as (1) a comparison of nine procedures for extracting phosphorus insecticides and their metabolites from field-treated crops, (2) a review of procedures for extracting organophosphate pesticides from water samples, (3) a review of insecticide recoveries from vegetables, (4) a review of various clean-up procedures, (5) a description of various detectors, (6) extensive data comparing the relative retention times of various pesticides on various column materials, and (7) a review of the sensitivity of various gas chromatographic systems.

Multi-Residue Methods -

Multi-residue methods for malathion are described in the AOAC's methods manual and PAM, Volume I. Zweig and Sherma (1972) have compiled a detailed review of gas chromatographic residue analyses.

AOAC Methods - One of the AOAC methods, a general method for "chlorinated and phosphated pesticides," is an "Official First Action" and applies only to apples and lettuce. A second AOAC multi-residue method applies only to "phosphated pesticides" (in kale, endive, carrots, lettuce, apples, potatoes, and strawberries). This second method is also an "Official First Action" and involved a sweep codistillation cleanup for the organophosphate residues. (The cleanup is not adequate for electron capture detectors; KCl thermionic detectors must be employed.) Also described in AOAC methods manual is a single sweep oscillographic-polarographic confirmation method.

The following AOAC multi-residue method is used for chlorinated and phosphated pesticides: a thoroughly mixed sample is extracted with acetonitrile. Aliquots of the acetonitrile solution are diluted with water and the pesticide residues are extracted into petroleum ether. The residues are purified by chromatography on a Florisil column and are eluted from the column with mixtures of petroleum and ethyl ethers. The first eluate (6% ethyl ether in petroleum ehter) contains some chlorinated pesticides and some phosphated pesticides. Methyl parathion, parathion, and diazinon are obtained in a second eluate (15% ethyl ether in petroleum ether). A third eluate (50% ethyl ether in petroleum ehter) contains malathion. The eluates are concentrated, and the residues are determined by gas chromatography and identified by combinations of gas, thin-layer, or paper chromatography.

PAM Procedures - The PAM multi-residue methods (PAM, 1971) apply to the wide variety of foods tested by the FDA. However, the multi-residue methods are not capable of detecting and measuring all pesticides. Analytical schemes used in the detection of malathion are shown in Figures 1 and 2. The various parts of the schemes shown in Figures 1 and 2 are outlined in detail in the PAM. (The numbers refer to the chemical numbering system of PAM; the chapter numbers also refer to PAM.)

Malathion is more than 80% recovered in the 50% ethyl ether in petroleum ether fraction from the Florisil column. Over 80% recovery is achieved from nonfatty foods (no data are available for fatty foods).

Relative retention times of malathion are presented in various column packing in the illustration that follows:

Electron Capture Detector

Column packing	Retention time relative to aldrin (ratio)	Response (ng for 1/2 FSD* at 1 x 10^{-9} AFS**)
10% DC 200 on Gas-Chrom Q (or Anakrom Q)	0.87	20-30
15% QF-1, 10% DC 200 on Gas-Chrom Q	1.48	20-30

Sulfur Detector

Column packing	Retention time relative to sulphenone (ratio)	Response (µg for 112 FSD* 64 ohms)
10% DC 200 on Gas-Chrom Q	0.71	0.75
15% QF-1, 10% DC 200 on Gas-Chrom Q	0.55	0.75

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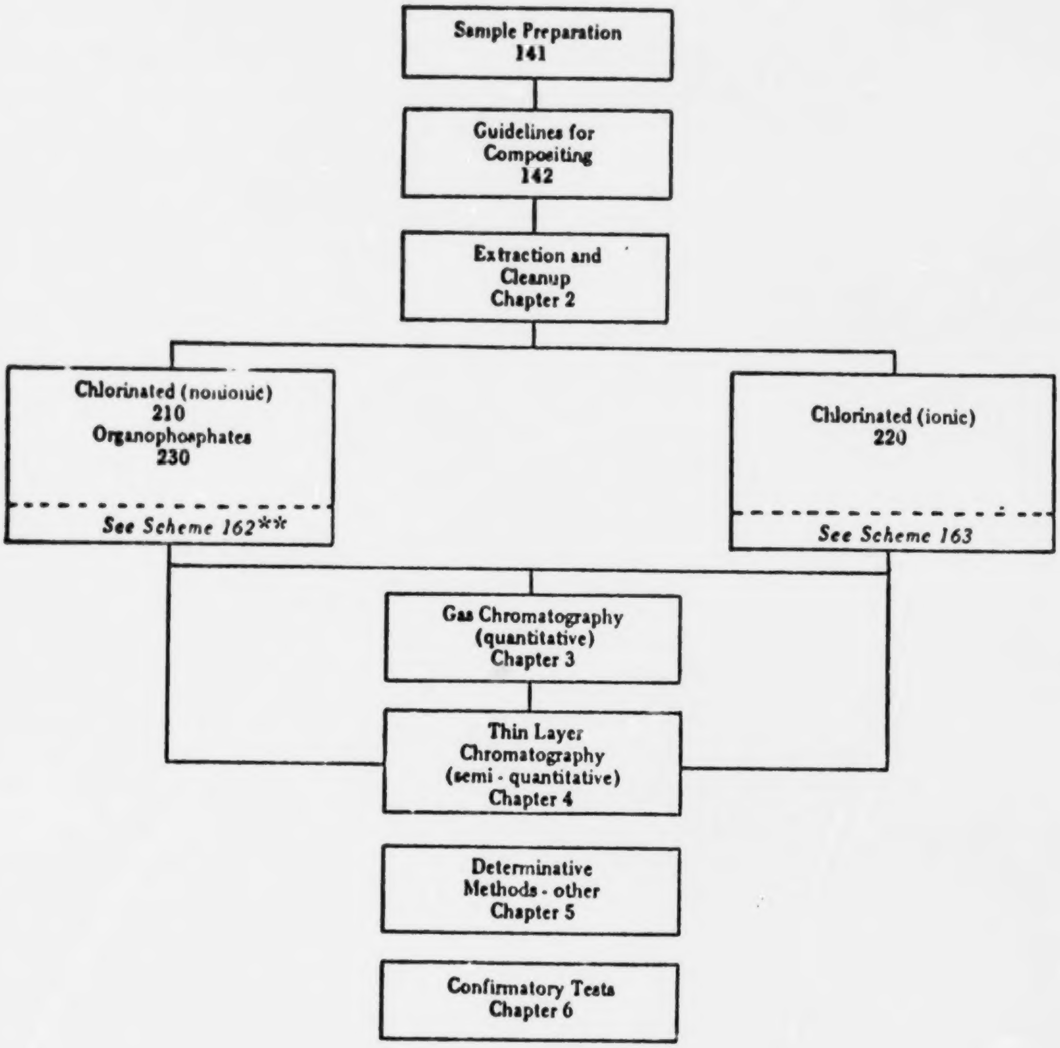
* FSD = Full scale deflection.

** AFS = Amps, full scale.

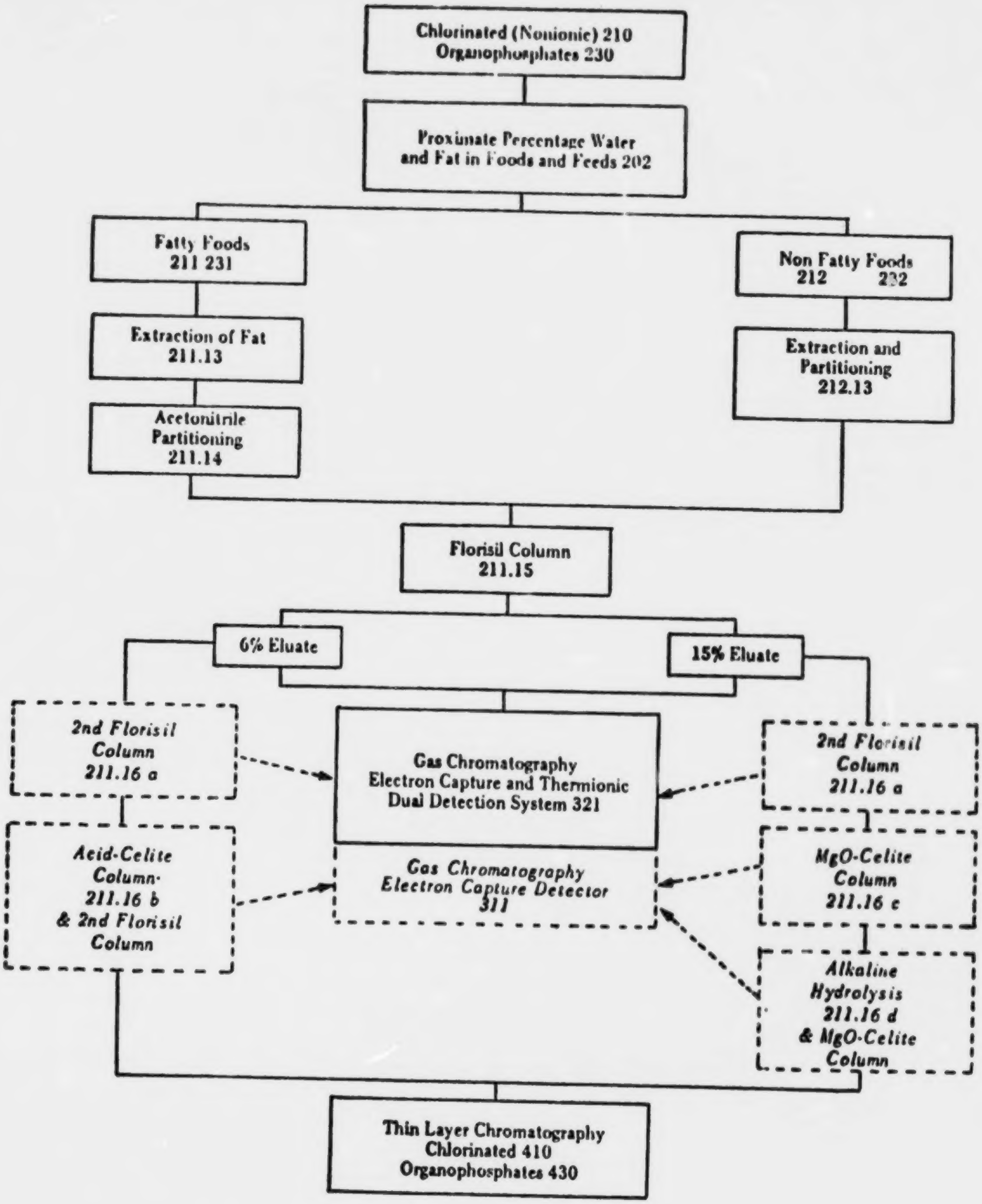

Sample Preparation
141
Guidelines for
Compositing
142
Extraction and
Cleanup
Chapter 2
Chlorinated (nonionic)
210
Organophosphates
230
See Scheme 162**
Chlorinated (ionic)
220
See Scheme 163
Gas Chromatography
(quantitative)
Chapter 3
Thin Layer
Chromatography
(semi - quantitative)
Chapter 4
Determinative
Methods - other
Chapter 5
Confirmatory Tests
Chapter 6

* The numbers refer to the decimal numbering system of PAM. Chapter numbers also refer to PAM.

** Scheme 162 is presented in Figure 2.

Source: PAM (1971).

Figure 2. General scheme for multiple residues*


Chlorinated (Nonionic) 210
Organophosphates 230
Proximate Percentage Water and Fat in Foods and Feeds 202
Fatty Foods 211 231
Non Fatty Foods 212 232
Extraction of Fat 211.13
Extraction and Partitioning 212.13
Acetonitrile Partitioning 211.14
Florisil Column 211.15
6% Eluate
15% Eluate
2nd Florisil Column 211.16 a
Gas Chromatography Electron Capture and Thermionic Dual Detection System 321
2nd Florisil Column 211.16 a
Acid-Celite Column 211.16 b & 2nd Florisil Column
Gas Chromatography Electron Capture Detector 311
MgO-Celite Column 211.16 c
Alkaline Hydrolysis 211.16 d & MgO-Celite Column
Thin Layer Chromatography Chlorinated 410 Organophosphates 430

* The numbers refer to the decimal numbering system of PAM. The primary analytical scheme is in bold type. Additional cleanup and/or quantitation schemes are in italics.

Source: PAM (1971).

Figure 3. Analytical scheme for chlorinated (nonionic) and organophosphate residues*

Potassium Chloride Thermionic Detector

Column packing	Retention time relative to parathion (ratio)	Response (mg for 1/2 FSD*)
10% DC-200 on Chromosorb W-HP (or Gas Chrom Q)	0.90	5
15% QF-1 + 10% DC 200 on Chromosorb W-HP (or Gas Chrom Q)	0.79	3

---

* FSD = Full scale deflection.

The PAM does not provide response data for flame photometric detectors. However, this type of detector is now widely used for the analysis of organophsophate residues, primarily because of the high degree of specificity in detecting phosphorus compounds. A review of these and other detectors is provided by Zweig and Sherma (1972).

Residue Analysis Principles -

Both AOAC "Methods of Analysis" (1970) and PAM (Vol. II) describe methods for the specific analysis of malathion residues. Zweig and Sherma have also provided a review of specific residue analytical methods for malathion.

AOAC Method (Official First Action) - According to the AOAC method for specific analysis of malathion residues, malathion is extracted with carbon tetrachloride or 2-propanol-carbon tetrachloride, and decomposed by alkali in carbon tetrachloride-alcohol solution to sodium 0,0-dimethyl phosphorodithioate, sodium fumarate and alcohol. The sodium 0,0-dimethyl phosphorodithioate is converted to a cupric salt which is soluble in carbon tetrachloride with the formation of an intense yellow color. The color intensity is proportional to the concentration of 0,0-dimethyl phosphorodithioic acid and is measured photometrically at 418 nm. (The color is only stable for 5 to 10 min.)

PAM Methods - PAM lists three methods for specific residue analysis. The first two methods have been "tested in varying degrees and are considered reliable without further validation for the product applications indicated." The third method has not been "thoroughly tested through interlaboratory studies."

The First Method - This method refers to the PAM procedure for organophosphate (PAM, Volume I).

The Second Method - This method is, essentially, the AOAC method which is described in the preceding section. According to PAM (Volume II), the AOAC method is generally applicable to "firm fruits and all types of vegetables." The sensitivity is 0.2 ppm for fruit; 0.5 ppm for vegetables. Interferences from other pesticides, oxidizable materials and metallic ions are discussed by Norris et al. (1954)[1] and Conroy (1959).[2]

The Third Method - The third method is used for the determination of malathion residues in fat, liver, meat, eggs and milk in concentrations down to 1.0, 1.0, 0.5, 0.5, and 0.02 ppm, respectively (freeze-drying apparatus is required for milk). The method was developed by Norris et al. (1958)[3] and is a modification and adaptation of the procedure of Norris et al. (1954).

Formulation Analysis Principles-

Three formulation analysis procedures for malathion are described in AOAC "Methods of Analysis" (1970). Zweig and Sherma have recommended a gas chromatographic method for the analysis of malathion formulations. A high pressure liquid chromatographic procedure is used by the Technical Service Division, Office of Pesticide Programs of EPA.

---

[1] Norris, M. V., W. A. Vail, and P. R. Averell, "Colorimetric Estimation of Malathion Residues," *J. Agr. Food Chem.*, 2:570-573 (1954).

[2] Conroy, H. W., "Report on Malathion," *J. Assoc. Off. Agr. Chem.*, 42: 551 (1959).

[3] Norris, M. V., E. W. Easter, L. T. Fuller, and E. J. Kuchar, "Colorimetric Estimation of Malathion Residues in Animal Products," *J. Agr. Food Chem.*, 6:111-114 (1958).

AOAC Methods - The following formulation analysis methods are presented.

Infrared Spectrophotometric Method (Official Final Action) - This method is applicable to dusts, dust base concentrates, and wettable powders where malathion is the only active ingredient. Other extractable organic materials such as dispersing agents, emulsifiers, and solvents may interfere and should be tested for interference. Sulfur does not interfere. The method involves the comparison of infrared spectra (11.0 to 13.0 um) of solutions of unknown and standard malathion in acetonitrile.

Colorimetric Method (Official First Action) - This method is similar to the previously described AOAC method for specific residue analysis. Malathion is decomposed by alkali in alcohol and the sodium 0,0-dimethyl phosphorodithioate is converted to a cupric complex solution in cyclohexane with formation of an intense yellow compound whose intensity is proportional to the concentration of 0,0-dimethyl phosphorodithioic acid and which is measured colorimetrically at 420 nm.

Ferric reagent is added to oxidize materials which would reduce cupric to cuprous ions. With phosphorodithioic acid, cuprous ions form a colorless complex which is apparently more stable than the yellow cupric complex.

The method is applicable to emulsifiable liquids and wettable powders and dusts, including those containing sulfur. Captan and carbaryl interfere. Before application of this method to mixtures, the affect of unfamiliar components should be specifically determined.

The procedure for this method has recently been updated (1973).[1]

Argentimetric Method (Official First Action)[2] - Malathion is cleaved in alkaline solution to dimethyl phosphorodithioate ion which forms an insoluble precipitate with silver ion. Malathion concentrations are determined by potentiometric titration of the hydrolyzed malathion using silver nitrate.

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[1] "Malathion: Colorimetric Method - Official First Action," J. Assoc. Off. Anal. Chem., 56(2):461 (1973).

[2] "Malathion: Argentimetric Method - Official First Action," J. Assoc. Off. Anal. Chem., 56(2):460 (1973).

Gas Chromatographic Method - According to a method recommended by Zweig and Sherma, liquid samples or acetonitrile extracts of solid samples are diluted to appropriate volume with acetonitrile and the malathion content determined by a gas chromatographic procedure employing an internal standard technique.

EPA Method - The following formulation analysis method is presented.

High Pressure Liquid Chromatographic Method - The Technical Service Division of EPA employs a high pressure liquid chromatographic method. This method[1/] is summarized as follows:

1. Equipment - High pressure liquid chromatograph with UV detector at 254 nm. Operating conditions must be determined for the individual liquid chromatograph being used to achieve optimum sensitivity and resolution. Adjustments in attenuation or amount injected should be made to give convenient size peaks.

2. Preparation of standard - Weigh 0.06 g malathion standard into a 10 ml volumetric flask and make to volume with methanol.

3. Preparation of sample - For liquids: weigh a portion of sample equivalent to 0.6 g malathion into a 100 ml volumetric flask and make to volume with methanol. For dust: weigh a portion of sample equivalent to 0.6 g malathion into 250 ml Erlenmeyer flask, add 100 ml methanol, and shake for 1 to 2 hr.

4. Procedure - Using a high pressure liquid syringe, alternately inject three 5 μl portions each of standard and sample solutions. Measure the peak area for each peak and calculate the average for both standard and sample.

[1/] Bontoyan, Warren R., Technical Services Division, Office of Pesticide Programs, Environmental Protection Agency, Personal Communication (September, 1974).

Composition and Formulation

Impurities in Malathion - Technical malathion is a minimum 95% pure. Among the very minor but controlled maximum impurities are methyl mercaptan (controlled to 30 ppm maximum to avoid odors) and iron (limited to 10 ppm maximum to prevent gel formation).

More important are the organophosphate impurities present in malathion. Although the median lethal dosage (LD_{50}) of technical malathion to rats orally is 1,000 mg/kg (range 390 to 2,100), the LD_{50} for these impurities is much lower. The impurities detected in technical malathion by Pellegrini and Santi (1972)[1/] (using a thin-layer chromatographic method) are as follows:

Code Name	Formula	Concentration of impurities (%)	LD_{50} of pure impurity
TES	$(MeO)_2P(S)(SMe)$	1	450
OTE	$(MeO)_2P(O)(SMe)$	0.1	47
ITE	$(MeS)_2P(O)(OMe)$	0.02	96

These compounds greatly increase the toxicity of technical malathion compared to pure malathion.

Pellegrini and Santi (1972) determined an LD_{50} of 1,580 mg/kg for 92.2% malathion, but 98% purified malathion had an LD_{50} of 8,000 mg/kg. The marked decrease in the LD_{50}, which is produced by less than 2% total of these organophosphate impurities, is caused by a potentiation effect. (When the compounds are mixed, their toxicity effect is synergistic, not additive.)

Pellegrini and Santi (1972) present data showing this potentiation effect for each of the impurities separately. In these tests, measured quantities of each impurity were added to pure malathion (98% purity), and the LD_{50} was determined at each level. Results are shown in Table 2.

[1/] Pellegrini, G., and R. Santi, "Potentiation of Toxicity of Organo-Phosphorus Compounds Containing Carboxylic Ester Functions Toward Warm-Blooded Animals by Some Organophosphorus Impurities," J. Agr. Food Chem., 20(5):944-950 (1972).

Table 2. POTENTIATING ACTION OF SOME ORGANOPHOSPHATES ON MALATHION

Code name	Percent impurity	Rat oral LD_{50} (mg/kg)
TES	0	8,000
	3	5,500
	3.5	4,000
	4	3,000
ITE	0	8,000
	0.02	5,200
	0.035	4,450
	0.1	2,920
	0.2	2,100
	0.5	1,240
	1.0	605
OTE	0	8,000
	0.1	3,900
	0.2	2,770
	0.3	2,150

Source: Adapted from Pellegrini and Santi, *op. cit.* (1972).

A homolog of malathion, the 0,0-dimethyl phosphorodithioate of ethyl butyl mercaptosuccinate, was found with malathion as a residue on crops (Gardner et al., 1969[1/]). This homolog (which contains a butyl rather than ethyl group on one of the carboxyl groups of the succinic acid portion of the molecule) is believed to be a contaminant in the commercial product rather than a chemical degradation product of malathion. No percentages of contamination are given.

Major Formulations - The major formulations of malathion are dusts (concentrated and dilute dusts and wettable powders), liquid formulations (emulsifiable liquids, a solubilized formulations and oil-based formulations)

[1/] Gardner, A. M., J. N. Damico, E. A. Hansen, E. Lustig, and R. W. Storherr, "Previously Unreported Homolog of Malathion Found as Residue on Crops," J. Agr. Food Chem., 17(6):1181-1185 (November-December 1969).

and a variety of other special preparations. A brief description of representative formulations is presented below (American Cyanamid, 1973,[1] Yost et al., 1955 a and b[2,3]).

Dusts and Wettable Powders - Dust concentrates, dilute dusts and wettable powders represent a major class of malathion formulations. These preparations are widely used in the various insect pest control practices for which malathion is now registered. Knowledge of the inherent properties of malathion and the carriers and diluents used is essential for the production of formulations which have good shelf life expectancy and satisfactory physical characteristics.

Another important factor in the successful preparation of stable malathion formulations is the nature of the carrier surface. Surfaces which tend to be catalytic, i.e., contain metallic ion, metallic oxide or other surface "hot spots," may contribute to malathion breakdown during long-term storage. These detrimental effects are especially pronounced in dilute formulations prepared directly on highly sorptive clays or where dust concentrates are diluted with them.

Perhaps the most important factor in the stability of malathion formulations is the temperature encountered during storage. Numerous powder-type formulations of malathion can be prepared having good shelf life when stored at 25°C. However, selection of carrier and diluent becomes very critical at more elevated storage temperatures, especially in the 37 to 45°C temperature range. Formulations should be stored in as cool a location as possible. Where relatively high storage temperature is anticipated, formulation ingredients should be carefully selected and blends prepared to minimize moisture effects, acid-base effects and carrier surface influences.

Use of carriers having low moisture content is also essential to the successful formulation of malathion. Based on present knowledge, calcined carriers, notably clays, should not be used with malathion if they have picked up appreciable moisture (more than 2%) during storage following calcination.

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[1] American Cyanamid, Agricultural Division, Manual for Insecticide Formulators (1973).

[2] Yost, J. F., J. B. Frederick, and V. Migrdichian, "Some Stability, Compatibility and Technological Findings on Malathion and Its Formulations (Part I)," Agr. Chemicals, 10(9):43-45 (September 1955a).

[3] Yost, J. F., J. B. Frederick, and V. Migrdichian, "Stability, Compatibility, Technological Data on Malathion Formulations (Part II)," Agr. Chemicals, 10(10):42-44, 105-107 (October 1955b).

Dust Concentrates - Suggested specific formulas for malathion dust concentrates are as follows (American Cyanamid, 1973):

Malathion 25% Dust Concentrates

Formula Type A

Ingredients	% by weight	
Malathion 95% grade	27.5 or	27.5
Celite 209 diatomaceous earth	18.0	27.5
Kaolin clay (acidic condition)	54.5	45.0
Total	100.0%	100.0%

Formula Type B

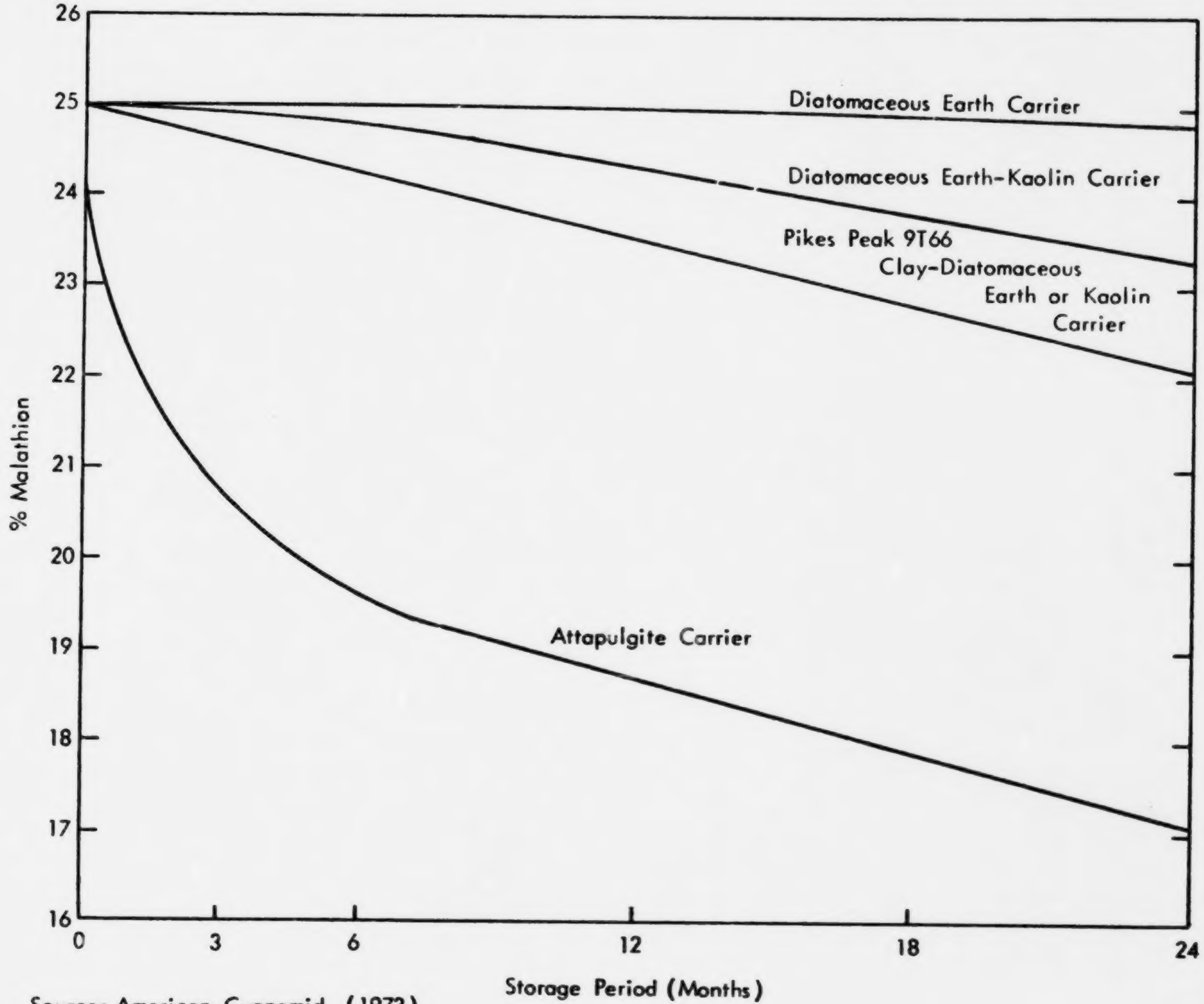
Ingredients	% by weight	
Malathion 95% grade	27.5 or	27.5
Celite SSC diatomaceous earth	18.0	27.5
Pikes Peak 9T66 clay (calcined condition)	54.5	45.0
Total	100.0%	100.0%

Formula Type C

Ingredients	% by weight
Malathion 95% grade	27.5
Kaolin clay (acidic condition)	27.5
Pikes Peak 9T66 clay (calcined condition)	45.0
Total	100.0%

The effect of carriers on the stability of malathion dust concentrated is indicated in Figure 2.

Dilute Dusts - Dilute malathion dust formulations are best prepared by diluting concentrated dusts with nonsorptive carriers or by direct impregnation of nonsorptive carriers. Sorptive carriers include such materials as diatomaceous earth, kaolinite, montmorillonite or volcanic dust. Nonsorptive carriers include aluminum silicate, calcium carbonate, calcium sulfate, talc and others.



Source: American Cyanamid (1973)

Figure 4. Effect of carriers on the stability of malathion dust concentrates.

Dilute dusts prepared directly on sorptive carriers deteriorate rapidly even at 25°C. Thus, the desired procedure is to dilute a dust concentrate with a nonsorptive diluent. Most extensively investigated for this purpose have been the pyrophyllite and neutral talc diluents. Both are excellent choices for use with malathion.

Good stability has also been noted for most dilute dust preparations made by direct impregnation on nonsorptive type diluents.

Wettable Powders - The chemical and physical properties of malathion formulations are similar for both wettable powder and dust concentrates. Thus, recommended formulas for malathion wettable powders are similar to those for dust concentrates.

Liquid Formulations - A number of different malathion liquid formulations are now marketed. Liquid formulations include solutions, emulsifiable liquid concentrates, oil-in-water emulsions, oil-based formulations, fly sprays, and formulations suitable for use as spray fogs or mists.

Liquid formulations of malathion that contain excessive iron may form a gel. Formulation ingredients should be selected so as not to produce more than 15 ppm of iron in the finished product. Malathion contains a maximum 10 ppm of iron when manufactured. The moisture content of the finished product also should be of a low order of magnitude, preferably below 0.5%.

Since concentrated malathion liquid formulations have a tendency to gel if kept in contact with iron, glass-lined or stainless steel equipment is preferred for preparation of liquid formulations (copper also is attacked and therefore not suitable).

Suggested proportions of emulsifier, solvent and malathion for the preparation of 5 lb/gal (57%) malathion emulsifiable concentrate are:

Ingredients	Percent by weight
Malathion 95% grade	62
Xylene or xylene alternate	30
Emulsifier	8
Total	100

Higher concentrations (for example, 85% malathion) of malathion can be prepared with more efficient emulsifiers.

Other liquid formulations of malathion include: low-emulsifier citrus spray concentrates, solubilized malathion formulations, and oil-based formulations. Oil-based malathion formulations are essentially solutions of malathion in aromatic organic solvents such as No. 2 fuel oil or deodorized kerosene.

Miscellaneous Formulations - Many other special preparations containing malathion are now being marketed. These include aerosol formulations, special formulations for stored-product insect control, granular formulations (for insect control over water surfaces and in areas having dense foliage), spray and granular bait formulations (for control of fruit flies and houseflies), formulations for use on freshly painted surfaces, formulations for pet and human treatment and formulations for use on masonry surfaces.

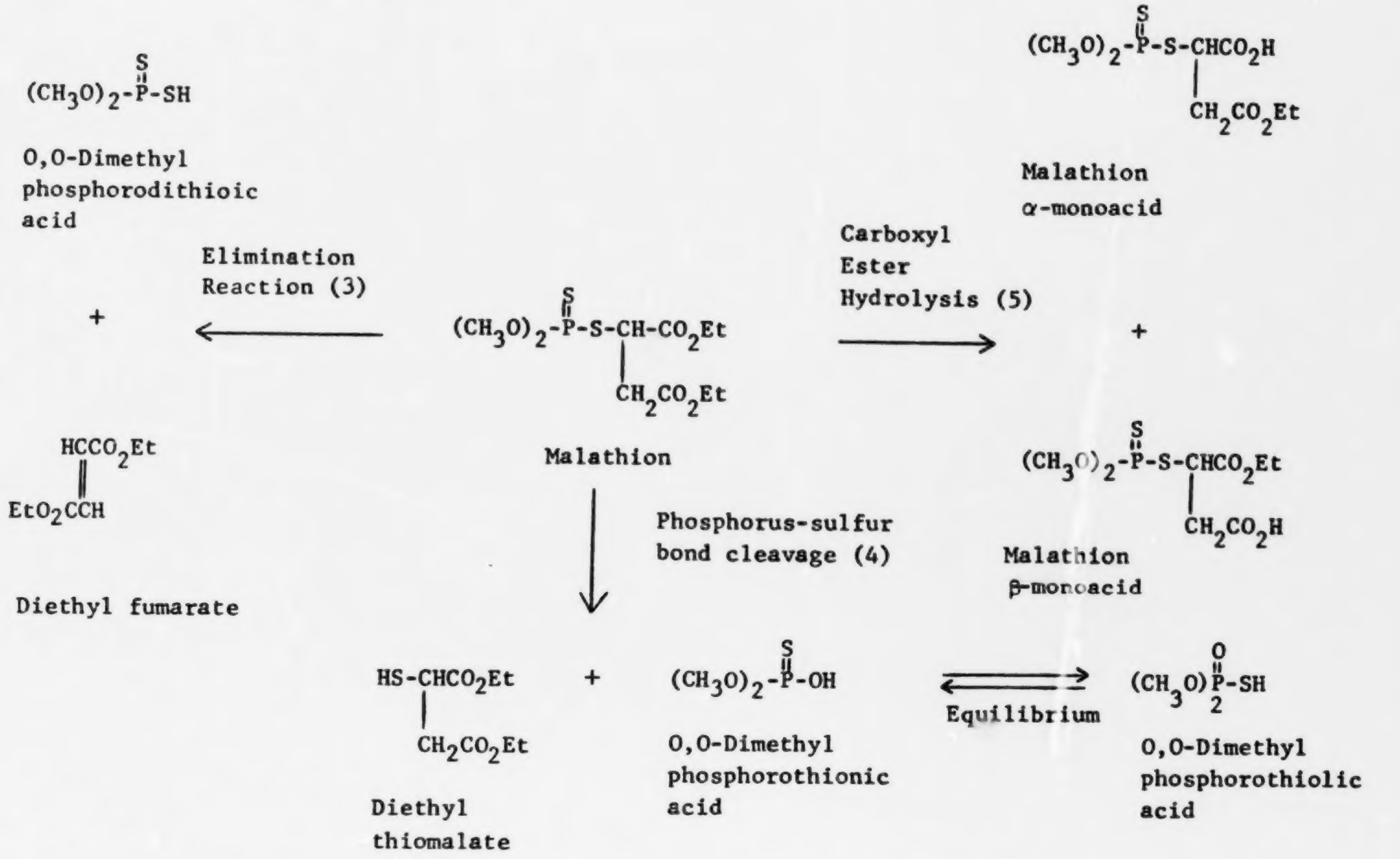
Chemical Properties, Reactions and Decomposition Processes

Hydrolysis is the most important decomposition reaction of malathion and has received the most intense investigation. Depending upon the reaction conditions, hydrolysis can occur via several different pathways leading to a variety of products. The thermal decomposition of malathion has also been investigated, but relatively little is known concerning the decomposition products. Malathion is readily oxidized to malaoxon, a reaction typical of other sulfur-containing organophosphate pesticides. Malathion is degraded by ultraviolet radiation, but little is known concerning this reaction. The chemical reactions of malathion are described in the following paragraphs.

Hydrolysis - Malathion has several chemical bonds that are subject to hydrolysis under environmental conditions (see Reactions (3), (4), and (5) in Figure 3). Sulfur-carbon cleavage proceeding through an elimination reaction (3) yields 0,0-dimethyl phosphorodithioic acid and diethyl fumarate. This is the predominant reaction during alkaline hydrolysis. Phosphorus-sulfur bond cleavage (Reaction (4)) yields diethyl thiomalate and 0,0-dimethyl phosphorothionic acid, which would be in equilibrium with its tautomer, 0,0-dimethyl phosphorothiolic acid. Carboxyl ester hydrolysis (Reaction (5)) yields a mixture of two products; malathion α- and malathion β-monoacids.

Spiller (1961)[1/] has reported that the stability of malathion in solution is a function of pH. Malathion was hydrolyzed "instantaneously" at pH 12.0, whereas at pH 9.0 about 50% was hydrolyzed in 12 hr.

[1/] Spiller, D., "A Digest of Available Information on the Insecticide Malathion," Adv. Pest Control Research, 4:249-335 (1961).



(CH3O)2-P(S)-SH
O,O-Dimethyl phosphorodithioic acid
+
HCCO2Et
EtO2CCH
Diethyl fumarate
Elimination Reaction (3)
(CH3O)2-P(S)-S-CH-CO2Et
CH2CO2Et
Malathion
Carboxyl Ester Hydrolysis (5)
(CH3O)2-P(S)-S-CHCO2H
CH2CO2Et
Malathion α-monoacid
+
(CH3O)2-P(S)-S-CHCO2Et
CH2CO2H
Malathion β-monoacid
Phosphorus-sulfur bond cleavage (4)
HS-CHCO2Et
CH2CO2Et
Diethyl thiomalate
+
(CH3O)2-P(S)-OH
O,O-Dimethyl phosphorothionic acid
Equilibrium
(CH3O)2P(O)-SH
O,O-Dimethyl phosphorothiolic acid

Adapted from Wolfe, N. L., R. G. Zepp, G. L. Baughman, and J. A. Gordon, Chemical and Photochemical Transformations of Selected Pesticides in Aquatic Systems, EPA, Office of Research and Development ROAP 21 AIM, Task 09 (Manuscript).

Figure 3. Chemical and photochemical transformations of selected pesticides in aquatic systems.

No hydrolysis could be detected after 12 days in solution of pH 5.0 to 7.0. In a similar study, Konrad et al. (1969)[1/] found that after 7 days at pH values of 11.0 and 9.0, 100 and 25%, respectively, of the malathion was hydrolyzed. At pH values of 2.0, 4.0, and 6.0, no degradation occurred in the same period. Cowart et al. (1971)[2/] reported that in a neutral aqueous solution, 59.3% hydrolysis occurred in 1 week.

Ruzicka et al. (1967b)[3/] found the half-life of malathion in ethanol pH 6.0 buffer solution (20:80) at 70°C to be 7.8 hr and reported the hydrolysis kinetics to be pseudo-first-order. In yet another pH study, Weiss and Gakstatter (1964)[4/] reported that malathion is not hydrolyzed at pH below 7.0 over prolonged periods.

Muhlmann and Schrader (1957)[5/] reported that, in alkaline solution, the primary hydrolysis products of malathion are diethyl fumarate and O,O-dimethyl phosphorodithioic acid (Figure 3, Reaction (3)). The primary products in acid solution are dimethyl phosphorothionic acid and diethyl thiomalate (Figure 3, Reaction 4). They also reported that the rate of hydrolysis increased fourfold with a 10°C increase in temperature.

Ketelaar and Gersmann (1958)[6/] confirmed the stoichiometry of the alkaline hydrolysis and determined the relative alkaline hydrolysis rates and energies of activation for malathion and 18 related compounds. (These hydrolysis studies were performed at pH 10.03 in 25% aqueous acetone.)

[1/] Konrad, J. G., G. Chesters, and D. E. Armstrong, "Soil Degradation of Malathion, a Phosphorodithioate Insecticide," Soil Sci. Soc. Am. Proc., 33(2):259-262 (March-April 1969).

[2/] Cowart, R. P., F. L. Bonner, and E. A. Epps, Jr., "Rate of Hydrolysis of Seven Organophosphate Pesticides," Bull. Environ. Contam. Toxicol., 6(3):231-234 (1971).

[3/] Ruzicka, J., J. Thomson, and B. B. Wheals, "The Gas Chromatographic Determination of Organophosphorus Pesticides. Part II. A Comparative Study of Hydrolysis Rates," J. Chromatog., 31:37 (1967b).

[4/] Weiss, C. M., and J. H. Gakstatter, "The Decay of Anticholinesterase Activity of Organic Phosphorus Insecticides on Storage in Waters of a Different pH," Adv. Water Pollution Research, 1:83 (1964).

[5/] Muhlmann, R., and G. Schrader, "Hydrolyse der Insektiziden Phosphoräurcester," Z. Naturforsch, 12b:196 (1957).

[6/] Ketelaar, J. A. A., H. R. Gersmann, "Chemical Studies on Insecticides. VI. The Rate of Hydrolysis of Some Phosphorus Acid Esters," Recueil des Travaux Chimiques des Pays-Bas (in English), 77:973-981 (1958).

Goldberg et al. (1968)[1] observed that, contrary to expectations, malathion hydrolyzed slowly on treatment with stoichiometric amounts of water at ambient temperatures in the pH range of natural water. Nuclear magnetic resonance measurements showed the half-life for the hydrolysis process to be greater than 2 weeks.

Kennedy et al. (1972b)[2] reported that malathion was not completely decomposed by 8N sodium hydroxide or 15N ammonium hydroxide (the contact times were not given). These investigators also stated that the treatment of malathion with triethanolamine produced no reaction. Based upon other data concerning the alkaline hydrolysis of malathion, it is surprising that these strongly alkaline reagents were not effective.

A comprehensive study of malathion hydrolysis was reported (Wolfe et al., 1974). Acid hydrolysis studies were performed (at pH 2.59) at elevated temperatures (67 and 87°C) because malathion is stable in water at this pH (very little decomposition occurred during 10 days at 27°C). This acid hydrolysis proceeds as indicated in Figure 5, (Reaction 5), but is much too slow to be significant at temperatures and pH values common to the aquatic environment (the half-life is greater than 1 year).

Additional hydrolysis studies were performed at pH 8 and 27°C (Wolfe et al., 1974). Half-life studies showed the presence of malathion, malathion monoacids, 0,0-dimethyl phosphorodithioic acid, and diethyl fumarate. The presence of these products demonstrates that two competing reactions are occurring, carboxyl ester hydrolysis and 0,0-dimethyl phosphorodithioic acid elimination (Figure 3, Reactions 3 and 5). Carboxyl ester hydrolysis is favored at lower temperatures, as shown by the amount of malathion monoacid present at one half-life; at 0°C there was 25%; at 27°C, 12%, and at 47°C, 5%.

Liquid chromatographic analysis showed that the monoacid mixture (27°C) consisted of 85% α-monoacid and 15% β-monoacid. The results indicate that chemical hydrolysis produces different products than does microbial degradation; Paris et al. (1974)[1] found that microbial degradation by aquatic organisms gave 99% malathion β-monoacid.

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[1] Goldberg, M., H. Babad, D. Groothius, and H. R. Christianson, "Nuclear Magnetic Resonance Studies of Phosphorus (V) Pesticides, III. The Hydrolysis of Aliphatic Pesticides by Aqueous Solutions," U.S. Geol. Survey Prof. Paper 600-D, pp. D20-D23 (1968).

[2] Kennedy, M. V., B. J. Stojanovic, and F. L. Shuman, Jr., "Analysis of Decomposition Products of Pesticides," J. Agr. Food Chem., 20(2): 341-343 (March-April 1972b).

Malathion monoacids are anticipated environmental degradation products and, therefore, their persistence under alkaline reaction conditions was examined (Wolfe et al., 1974). Assuming no large difference in reactivity for the two isomers, the monoacids have a half-life of about 24 days at pH 8. These data indicate that malathion monoacids are about 18 times more stable than malathion under the same alkaline (pH 8) conditions. Wolfe et al. (1974) have concluded these monoacids would be more persistent in the environment.

Konrad et al. (1969) observed that the rates of malathion degradation in soils were related directly to the extent of malathion adsorption. This observation suggested that degradation occurred by a chemical mechanism which was catalyzed by adsorption. Malathion degradation was rapid (50 to 90% in 24 hr, depending on the type of soil) in both sterile and nonsterile soil systems, and no lag phase occurred prior to degradation. In aqueous, soil-free systems inoculated with a soil extract, a lag phase (7 days) occurred, followed by rapid malathion loss, likely due to microbial degradation. Thus, in soils, complete chemical degradation of malathion probably occurs prior to microbial adaptation to malathion.

Thermal Decomposition - Malathion is a reasonably stable compound that undergoes some decomposition when held much above room temperature. Heating the purified, nearly colorless liquid for 24 hr at 150°C resulted in the formation of an orange-brown, viscous liquid and some colorless cloudy material which was immiscible (Metcalf and March, 1953).[2] This treatment resulted in the isomerization of approximately 90% of the original material. No decomposition products were identified.

McPherson and Johnson (1956)[3] examined the variation of decomposition time with temperature and, for malathion, obtained the following results.

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[1] Paris, D. F., D. L. Lewis, and N. L. Wolfe, "Rates of Degradation of Malathion by Bacteria Isolated from an Aquatic System," submitted for publication (1974).

[2] Metcalf, R. L., and R. B. March, "The Isomerization of Organic Thiophosphate Insecticides," J. Econ.Entomol., 46:288-294 (April 1953).

[3] McPherson, J. B., Jr., and G. A. Johnson, "Thermal Decomposition of Some Phosphorothioate Insecticides," J. Agr. Food Chem., 4(1): 42-49 (January 1956).

Temperature (°C)	Decomposition time (days)
115	5
100	20
80	163
65	925

The burning of malathion solutions was investigated by Smith and Ledbetter (1971).[1] Malathion solutions (1 g/10 ml) in xylene and kerosene were burned and gases collected above the fire were analyzed. Samples were collected at various intervals after the ignition of the solutions. The maximum malathion found from the burning malathion-xylene solutions was 10 $\mu g/m^3$ at 4.5 min after ignition, and that from the kerosene mixture was 4 $\mu g/m^3$ at 2.5 min. Smith and Ledbetter (1971) noted that these quite low concentrations could result from either a high efficiency of combustion or a failure of the malathion to evaporate during the burning.

Some of the decomposition products of malathion were identified during the experiments. Diethyl fumarate was separated and positively identified by infrared spectrophotometry. Some other compounds were tentatively identified by their retention times in gas chromatography. Compounds tentatively identified by Smith and Ledbetter (1971) were:

Methanol
Ethanol
Ethyl acetate
Diethyl fumarate
Isomers of dimethyl dithiophosphate
Malathion isomers

Smith and Ledbetter (1971) concluded that several factors tend to reduce the hazards from organophosphate (e.g., malathion) insecticides in fires. First, most of the pesticide is destroyed by decomposition before it can evaporate. Second, over 90% of the evaporating insecticide is destroyed by the flames. Third, the evaporating portion is considerably diluted by the time it reaches anyone.

Differential thermal analysis of malathion (Kennedy et al., 1969)[2] provided the following data.

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[1] Smith, W. M., Jr., and J. O. Ledbetter, "Hazards from Fires Involving Organophosphorus Insecticides," Amer. Ind. Hyg. Assoc. J., 32(7): 468-474 (July 1971).

[2] Kennedy, M. V., B. J. Stojanovic, and F. L. Shuman, Jr., "Chemical and Thermal Methods for Disposal of Pesticides," Residue Rev., 29:89-104 (1969).

Product	Endothermic peaks[a] (°C)	Exothermic peaks[a] (°C)
Pure malathion reference standard	500	250, 308, 333, 422
Commercial product (5 lb/gal)	145, 441, 475	261, 308

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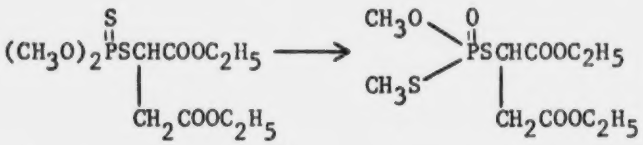
[a] Sensitivity 25%.

According to Melnikov (1971),[1] malathion, on prolonged heating at 150°C, is isomerized to the corresponding thiolo isomer:



At a higher temperature, this reaction proceeds violently and a considerable amount of the product is decomposed, sometimes even explosively.

The thermal decomposition of a commercial malathion formulation (5 lb/gal) at various temperatures was investigated by Kennedy et al. (1969). Extensive decomposition would have been expected at these high temperatures; thus the contact time, which was not reported, must have been very short, or the reported loss was equivalent to total decomposition. The results from this study are summarized as follows:

Temperature (°C)	Percent loss
600	95.3
700	96.0
800	96.3
900	96.4
1000	96.7

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[1] Melnikov, N. N., Chemistry of Pesticides, Springer-Verlag, New York, pp. 357-359 (1971).

Kennedy et al. (1969) further investigated the thermal decomposition of malathion (analytical grade). The investigators interpreted their data to indicate that maximum decomposition of malathion occurs at 350°C. The observed effects of heating on weight loss, color and physical appearance were as follows:

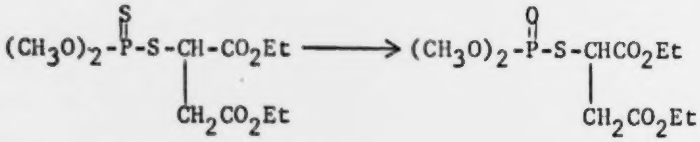
Heating time (min)	Temperature (°C)	Weight loss (%)	Color	Physical appearance
30	200	58.7	Dark-brown	Liquid
30	250	72.9	Dark-brown	Liquid, jelly-like on cooling
30	300	76.2	Dark-brown	Silk flakes
30	350	80.3	Dark-brown	Silk flakes
30	400	80.3	Dark-brown	Silk flakes
30	500	80.3	Dark-brown	Silk flakes
30	600	80.3	Dark-brown	Silk flakes

Additional data on the decomposition of malathion were reported by Stojanovic et al. (1972).[1/] In general, the same physical changes previously reported were observed when malathion was heated. Diethyl succinate, diethyl malate and diethyl fumarate were tentatively identified as decomposition products on the basis of infrared spectra.

The following products were identified in the gases obtained from the burning of analytical grade malathion at 900°C: carbon monoxide, carbon dioxide, sulfur dioxide, hydrogen sulfide and oxygen (Kennedy et al., 1972b). There were four other unidentified products.

[1/] Stojanovic, B. J., F. Hutto, M. V. Kennedy, and F. L. Shuman, Jr., "Mild Thermal Degradation of Pesticides," J. Environ. Quality, 1(4):397-401 (1972).

Oxidation - Malathion is readily oxidized to malaoxon by a variety of mild oxidizing agents (Wolfe et al., 1974):



$$(CH_3O)_2\text{-}\overset{S}{\overset{\|}{P}}\text{-}S\text{-}\underset{CH_2CO_2Et}{\underset{|}{CH}}\text{-}CO_2Et \longrightarrow (CH_3O)_2\text{-}\overset{O}{\overset{\|}{P}}\text{-}S\text{-}\underset{CH_2CO_2Et}{\underset{|}{CH}}CO_2Et$$

Malathion Malaoxon

Bromine water, for example, apparently achieves a quantitative conversion of malathion to malaoxon (Ruzicka et al., 1967a[1]). Nitric acid also is reported to effect this conversion (Melnikov, 1971).

Malathion is stable in oxygen-saturated, acidic water for up to 2 weeks (Wolfe et al., 1974). Therefore, oxidation of malathion by molecular oxygen does not appear to be environmentally significant.

The oxidation of malathion as a result of thermal decomposition or incineration is discussed in the preceding section.

Ultraviolet Radiation - Ultraviolet radiation decomposes malathion (Cook and Ottes, 1959, Mitchell, 1961[2,3]). When small quantities of malathion were placed on filter paper and irradiated by means of a germicidal lamp (254 nm), it was converted to compounds which were less polar than malathion. These compounds were not identified. Malathion photolysis half-life is 990 hr in distilled water (pH 6) with wavelengths greater than 290 nm. However, in a sample of Suwannee River water containing a large amount of colored material, malathion was 50% degraded by sunlight in 16 hr (Wolfe et al., 1974).

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[1] Ruzicka, J., J. Thomson, and B. B. Wheals, "The Gas Chromatographic Examination of Organophosphorus Pesticides and Their Oxidation Products," J. Chromatog., 30(1):92-99 (September 1967a).

[2] Cook, J. W., and R. Ottes, "Note on the Conversion of Some Organophosphate Pesticides to Less Polar Compounds by Ultraviolet Light," J. Assoc. Off. Agr. Chem., 42:211-212 (1959).

[3] Mitchell, L. C., "The Effect of Ultraviolet Light (2537 A) on 141 Pesticide Chemicals by Paper Chromatography," J. Assoc. Off. Agr. Chem., 44(4):643+ (1961).

Miscellaneous Reactions - Malathion, on prolonged contact with iron or iron-containing material, is reported to decompose and completely lose insecticidal activity (Melnikov, 1971).

Malathion is decomposed by Raney Nickel, producing diethyl succinate (70% yield) and an unidentified sulfur-free phosphorus product (Nagasawa, 1971[1]).

Malathion is decomposed within 1 hr by sodium or lithium in liquid ammonia (Kennedy et al., 1972a[2]). No decomposition products were reported.

Occurrence of Malathion Residues in Food and Feed Commodities

The Food and Drug Administration, Department of Health, Education, and Welfare, monitors pesticide residues in the nation's food supply through two programs. One program, commonly known as the "total diet program," involves the examination of food ready to be eaten. This investigation measures the amount of pesticide found in a high-consumption varied diet. The samples are collected in retail markets and prepared for consumption before analysis. The second program involves the examination of large numbers of samples, obtained when lots are shipped in interstate commerce, to determine compliance with tolerances. These analyses are complemented by observation and investigations in the growing areas to determine the actual practices being followed in the use of pesticide chemicals.

A majority of the samples collected in these programs are categorized as "objective" samples. Objective samples are those collected where there is no suspicion of excessive residues or misuse of the pesticide chemicals. All samples of imported foods and fish are categorized as "objective" samples even though there may be reason to believe excessive residues may be found on successive lots of these food categories.

Market-basket samples for the total diet studies are purchased from retail stores, bimonthly, in five regions of the United States.

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[1] Nagasawa, K., T. Yamada, and A. Ogamo, "Reductive Cleavage of Sulfur Containing Organophosphorus Compounds with Raney Nickel," Chem. Pharm. Bull., 19(11):2373-2379 (November 1971).

[2] Kennedy, M. V., B. J. Stojanovic, and F. L. Shuman, Jr., "Chemical and Thermal Aspects of Pesticide Disposal," J. Environ. Quality, 1(1):63-65 (1972a).

A shopping guide totaling 117 foods for all regions is used, but not all foods are represented in all regions because of differences in regional dietary patterns. The food items are separated into 12 classes of similar foods and prepared for consumption by dietitians in institutional kitchens. After preparation, the food items are composited into 12 classes of similar foods (e.g., dairy products; meat, fish and poultry; legume vegetables; and garden fruits) for more reliable analysis and to minimize the dilution factor. Each class in each sample is a "composite." The food items and the proportion of each used in the study was developed in cooperation with the Household Economics Research Division, U.S. Department of Agriculture, and represents the high-consumption level of a 16- to 19-year old male. Each sample represents a 2-week supply of food.

Surveillance samples are generally collected at major harvesting and distribution centers throughout the U.S. and examined in 16 U.S. Food and Drug Administration district laboratories. Some samples may be collected in the fields immediately prior to harvest. Surveillance samples are not obtained in retail markets. Samples of imported food are collected when offered for entry into the United States.

The results obtained during the 4-year period, fiscal 1965 to 1969, are compared in Table 3 with the acceptable daily intake (ADI) established by the FAO/WHO* Expert Committee (FAO/WHO, 1970[1/]). The amount of malathion and total organophosphates calculated from this high-consumption diet (approximately twice that consumed by a normal individual) are well below the daily intake regarded as safe by the FAO/WHO Expert Committee (Duggan et al., 1971[2/]). However, it should be noted that malathion accounts for almost all of the total dietary intake of organophosphates (see Table 3).

Table 4 compares the incidence and daily intake in milligrams of malathion found in these samples for each of the 4 years.

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* Food and Agriculture Organization of the United Nations - World Health Organization.

1/ FAO/WHO, *1969 Evaluations of Some Pesticide Residues in Food*, WHO/Food Add./70.38 (1970).

2/ Duggan, R. E., G. Q. Lipscomb, E. L. Cox, R. E. Heatwole, and R. C. King, "Pesticide Residue Levels in Foods in the United States from July 1, 1963 to June 30, 1969," *Pest. Monit. J.*, 5(2):73-212 (September 1971).

Table 3. DIETARY INTAKE OF MALATHION AND TOTAL ORGANOPHOSPHATES

Compounds	FAO/WHO acceptable daily intake	Mg/kg body weight/day total diet studies 1965-66	1966-67	1967-68	1968-69	4-Year average
Malathion	0.02	0.0001	0.0002	0.00004	0.0002	0.00013
Total organophosphates	--	0.00014	0.00025	0.00007	0.00023	0.00017

Adapted from Duggan et al., op. cit. (1971).

Table 4. AVERAGE INCIDENT AND DAILY INTAKE OF MALATHION

1965-66		1966-67		1967-68		1968-69	
Percent positive composites[a]	Daily intake (mg)	Percent positive composites[b]	Daily intake (mg)	Percent positive composites	Daily intake (mg)	Percent positive composites	Daily intake (mg)
5.3	0.009	3.6	0.010	1.9	0.003	5.8	0.012

---

[a] 312 Composites examined.

[b] 360 Composites examined.

Adapted from Duggan et al., op. cit. (1971).

The results of the FDA analytical studies are tabulated for the following food classes:

Dairy Products
Large Fruits
Small Fruits
Grains and Cereals (Human)
Leaf and Stem Vegetables
Vine and Ear Vegetables
Root Vegetables
Beans
Red Meat
Poultry
Eggs
Fish
Shellfish
Grains (Animal)
Infant and Junior Foods
Tree Nuts
Vegetable Oil Products

Summaries have been prepared (Duggan et al., 1971) for each of the above food classes from data obtained from samples shipped in interstate commerce and from samples imported into the United States during fiscal 1964-1969. Malathion was detected in only two of these food classes (grain and cereals for human use, and grains for animal consumption). These residue data are presented in Tables 5 and 6.

The most recently available analytical data are presented in Table 7 which lists the incidence and ranges of levels for malathion detected in grains and cereal for human use and grains for human consumption. No significant malathion residues were detected in the other food classes. These data cover the years 1964-1969. Limited data are available for the year 1970 (Corneliussen, 1972[1/]), and a complete update on pesticide residue data is expected in the forthcoming September 1974 issue of the Pesticide Monitoring Journal.

Duggan et al. have concluded that, in grains and cereals for human use, malathion residues are increasing in incidence and in concentration.

Acceptable Daily Intake

The acceptable daily intake (ADI) is defined as the daily intake which, during an entire life-time, appears to be without appreciable risk on the basis of all known facts at the time of evaluation (Lu, 1973[2/]). It is expressed in milligrams of the chemical per kilogram of body weight (mg/kg).

1/ Corneliussen, P. E., "Residues in Food and Feed: Pesticide Residues in Total Diet Samples (VI)," Pest. Monit. J., 5(4):313-329 (March 1972).

2/ Lu, F. C., "Toxicological Evaluation of Food Additives and Pesticide Residues and Their 'Acceptible Daily Intakes' for Man: The Role of WHO, in Conjunction with FAO," Residue Rev., 45:81-93 (1973).

Table 5. MALATHION RESIDUES IN CEREALS AND GRAINS FOR HUMAN USE
(Fiscal Years 1964-1969)

Raw agricultural products[a]	Number of samples examined	Incidence (%)	Average (ppm)
Domestic	8,005	22.1[c]	0.56
Imported	104	--	--
Total diet samples--ready-to-eat food[b]	134 (composites)	28.4	0.012

---

a/ Wheat, grain, corn, rice, etc.

b/ Grain and cereal composites: flour, bread, cornmeal, vegetable corn, rice, macaroni, pie crust, etc.

c/ Not included in analytical method, fiscal 1964 to 1965.

Adapted from Duggan et al., op. cit. (1971).

Table 6. MALATHION RESIDUES IN RAW DOMESTIC GRAIN PRODUCTS FOR ANIMAL CONSUMPTION
(Fiscal Years 1966-1969)

Raw Agricultural Products: Wheat, Grain Corn, Milo

Domestic	
Incidence (%)	Average (ppm)
18.3[a]	0.12

	Domestic
Number of samples examined	1,168
Percent with residues	40.6

---

a/ Not included in analytical method, fiscal 1964 to 1969.

Adapted from Duggan et al., op. cit. (1971).

Table 7. DISTRIBUTION OF MALATHION RESIDUES IN GRAINS AND CEREAL BY QUANTITATIVE RANGES (ppm)

	Percent distribution of samples							
	Domestic				Imported			
Range ppm	1964-1967	1968	1969	Total	1964-1967	1968	1969	Total
Grains and Cereal for Human Use								
No. samples	2,107	359	234	2,700	20	--	--	20
None found	89.93	38.72	29.49	77.89	100.00	--	--	100.00
< 0.00 - < 0.03	4.41	22.01	27.35	8.74	--	--	--	--
0.04-0.10	0.99	10.31	10.26	3.04	--	--	--	--
0.11-0.50	2.37	14.76	16.24	5.22	--	--	--	--
0.51-1.00	0.80	5.01	5.56	1.78	--	--	--	--
1.01-1.50	0.37	1.95	3.85	0.89	--	--	--	--
1.51-2.00	--	1.67	2.56	0.44	--	--	--	--
Above 2.00	1.09	5.57	4.70	2.00	--	--	--	--
Grains for Animal Consumption								
No. samples	710	119	19	848	45	1	--	46
None found	90.28	40.34	21.05	81.72	100.00	--	--	97.83
< 0.00 - < 0.03	2.25	18.49	36.84	5.31	--	100.00	--	2.17
0.04-0.10	1.54	14.29	5.26	3.42	--	--	--	--
0.11-0.50	4.08	18.49	10.53	6.25	--	--	--	--
0.51-1.00	0.70	5.88	--	1.42	--	--	--	--
1.01-1.50	0.14	0.84	--	0.24	--	--	--	--
1.51-2.00	0.14	0.84	10.53	0.47	--	--	--	--
Above 2.00	0.84	0.84	15.79	1.18	--	--	--	--

Data from Duggan et al., *op. cit.* (1971).

For malathion the ADI is 0.02 mg/kg. This level was set at the 1966 Joint Meeting of the FAO Committee on Pesticides in Agriculture and the WHO Expert Committee on Pesticide Residues (FAO/WHO, 1967a[1]). A joint meeting is held annually and new evidence is considered which would warrant a change in the ADI of any pesticide. The level for malathion has not been changed through 1971 (FAO/WHO, 1972[2]).

In making the evaluation, all available research on malathion concerning its biochemical effects, toxicology, and teratology is considered.

Tolerances

U.S. Tolerances - Section 408 of the Food, Drug and Cosmetic Act, as amended, gives procedures for establishing tolerances for pesticide chemicals on raw agricultural commodities. Section 409 applies to food additives, including pesticide chemicals on processed foods. Tolerances are published in the Code of Federal Regulations, Title 40, and in the Federal Register. A summary of current U.S. tolerances for malathion on raw agricultural commodities is presented in Table 8.

According to Lu (1973), U.S. tolerances which are established should not result in the maximum ADI being reached each day. He gives the following reasons:

1. The tolerance reflects the maximum level of residue resulting from good agricultural practice, but this level is often not reached.
2. The tolerance is based on the assumption that the particular pesticide is used on all food in the class in question, and this is rarely the case.
3. Much of the residue will be lost in storage, processing and cooking.

The tolerances are also based upon the entire product as purchased in the market. However, the product, as purchased, may not be entirely consumed.

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[1] FAO/WHO, Evaluation of Some Pesticide Residues in Food, WHO/Food Add./67.32 (1967a).

[2] FAO/WHO, "Pesticide Residues in Food," Report of the 1971 Joint FAO/WHO Meeting on Pesticide Residues, World Health Organization Tech. Rept. Series No. 502 (1972).

Table 8. U.S. TOLERANCES FOR MALATHION ON RAW AGRICULTURAL COMMODITIES

ppm	Crop
135	Alfalfa
8	Almonds
50	Almond hulls
8	Anise
8	Apples
8	Apricots
8	Asparagus
8	Avocados
8	Barley
8	Beans
8	Beets (including tops)
8	Blackberries
8	Blackeye peas
8	Blueberries
8	Boysenberries
8	Broccoli
8	Brussels sprouts
8	Cabbage
8	Carrots
4	Cattle, beef - meat, fat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
0.5	Cattle, dairy - in milk fat
8	Cauliflower
8	Celery
8	Cherries
1	Chestnuts
135	Clover
8	Collards
8	Corn forage
8	Corn grain
2	Corn (kernels plus cob with husk removed)
2	Cottonseed
8	Cowpeas
135	Cowpea (hay and forage)
8	Cranberries
8	Cucumbers
8	Currants
8	Dandelions
8	Dates
8	Dewberries
0.1	Eggs (from application to poultry)
8	Egg plants
8	Endive (escarole)
8	Figs
1	Filberts
8	Garlic
4	Goats - meat, fat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
8	Gooseberries
8	Grapefruit
8	Grapes
135	Grass
135	Grass hay
8	Guavas
1	Hops
8	Horseradish
4	Horses - meat, fat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
8	Kale
8	Kohlrabi
8	Kumquats
8	Leeks
8	Lemons
8	Lentils
135	Lespedeza (hay and straw)
8	Lespedeza seed
8	Lettuce
8	Limes
8	Loganberries
135	Lupine (hay and straw)
8	Lupine seed
1	Macadamia nuts
8	Mangoes
8	Melons
0.5	Milk (from applications to dairy cows)
0.5	Milk fat (from applications to dairy cows)
8	Mushrooms
8	Mustard greens
8	Nectarines
8	Oat
8	Okra
8	Onions (including green onions)
8	Oranges
1	Papayas
8	Parsley
8	Parsnips
8	Passion fruit
8	Peaches
135	Peanut (hay and forage)
8	Peanuts
8	Pears
8	Peas
8	Peavines
8	Peavine hay
8	Pecans
8	Peppermint
8	Peppers
8	Pineapples
8	Plums
8	Potatoes
4	Poultry - meat, fat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
8	Prunes
8	Pumpkins
8	Quinces
8	Radishes
8	Raspberries
8	Rice
8	Rutabagas
8	Rye
0.6	Safflower oil
0.2	Safflower seed
8	Salsify (including tops)
8	Shallots
4 0.2	Sheep - fat, meat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
8	Sorghum forage
8	Sorghum grain
8	Soybeans (dry and succulent)
135	Soybean (forage and hay)
8	Spearmint
8	Spinach
8	Squash (summer and winter)
8	Strawberries
1	Sugar beet roots
8	Sugar beet tops
1	Sweet potatoes
4	Swine - meat, fat, meat by-products (not to be exceeded in any cut of meat or meat by-products)
8	Swiss chard
8	Tangelos
8	Tangerines
8	Tomatoes
8	Turnips (including tops)
135	Vetch (hay and straw)
8	Vetch seed
8	Walnuts
8	Watercress
8	Wheat

Source: EPA Compendium of Registered Pesticides, Vol. III, U.S. Environmental Protection Agency (1973).

International Tolerances - Tolerances established by individual nations may be based on recommendations of the FAO/WHO Expert Committee on Food Additives. The Committee evaluates all residue data submitted by interested parties and uses the following criteria (FAO/WHO, 1962,[1] for making tolerance recommendations:

1. Decide upon the effective level of the food additive under consideration that would be needed in good technological practice.

2. Examine the possible uses and list all the foods in which the food additive might be used.

3. Calculate the daily intake level that might occur if the food additive was used in all the foods for which it might be a useful additive, working on the basis of the average intake of the food materials containing the additive. This average intake for appropriate population groups is obtained from national food consumption surveys.

4. Obtain the necessary information from which to calculate the average body weight of the population group concerned (usually between 50 to 70 kg).

5. From this information, calculate the intake of the additive in milligrams per kilograms of body weight per day.

6. Check the figure against the acceptable intakes given for the substances in the table. If it falls within the unconditional intake zone, the situation is satisfactory and the level proposed may be accepted. If it falls within the conditional intake zone, further scientific advice is required before the level of use proposed is accepted.

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[1] FAO/WHO, Food and Agricultural Organization of the United Nations/ World Health Organization, "Evaluation of the Toxicity of a Number of Antimicrobials and Antioxidants," Sixth Report, Joint FAO/WHO Expert Committee on Food Additives, World Health Organization Tech. Rept. Series No. 228, Geneva (1962).

The validity of the above criteria was reaffirmed at the 1966 FAO/WHO meeting (FAO/WHO, 1967b[1]).

Table 9. MALATHION TOLERANCES ESTABLISHED BY FAO/WHO

	ppm
Raw cereals, nuts, dried fruits	8
Whole meal and flour from rye and wheat	2
Citrus fruit	4
Blackberries, raspberries, lettuce, endive, cabbage, spinach	8
Cherries, peaches, plums	6
Broccoli	5
Tomatoes, kale, turnips	3
Beans (green), apples	2
Strawberries, celery	1
Pears, blueberries, peas (in pods), cauliflower, peppers, eggplant, kohlrabi, roots (except turnips), Swiss chard, collards	0.5

Adapted from FAO/WHO, op. cit. (1972).

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[1] FAO/WHO, "Specifications for the Identify and Purity of Food Additives and Their Toxicological Evaluation: Some Emulsifiers and Stabilizers and Certain Other Substances," 10th Report, Joint FAO/WHO Expert Committee on Food Additives, World Health Organization Tech. Rept. Series No. 373 (1967b).

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SUBPART II. B. PHARMACOLOGY AND TOXICOLOGY

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This section is concerned with information on the acute, subacute and chronic toxicities of malathion; a brief review is also given of the characteristic symptoms and pathology. The metabolism of malathion is discussed as related to its absorption, distribution, excretion, biotransformation, and tissue accumulation. Other subjects that have been reviewed are the effects of malathion on reproduction, malformation of the young, behavioral effects, and the toxic effects of this pesticide to tissue cultures. There were no studies found on the ability of malathion to produce mutagenesis and/or oncogenic effects in laboratory animals. The hazards posed by the exposure of humans to malathion have been reviewed in relation to acute and subacute toxicity, the symptoms associated with malathion poisoning, the routes of exposure (mainly dermal and respiratory), and the hazards associated with the use of malathion in field operations. The section summarizes rather than interprets scientific data reviewed.

Additional data on the acute toxicity of malathion can be found under the subsection on Analytical Methods, p. 23.

Acute, Subacute and Chronic Toxicity

The information in this subsection is related to the toxicological studies of laboratory and domestic animals.

Toxicity to Laboratory Animals

Acute oral toxicity - rats - The results of a number of tests for the acute oral toxicity of malathion to rats are shown in Table 10. The vehicle and formulation have a considerable influence on absorption following oral administration. Early samples of the technical material were 65 to 77% pure, while later materials approximated 90 to 99%. The acute oral toxicity of malathion to mammals appeared to vary inversely with the degree of purity of the compound (Hazelton and Holland, 1953[1/]). In one study, when rats were exposed to the compound, males were more susceptible to malathion than females (Hazleton and Holland, 1953). However, this difference in susceptibility between the sexes was not shown in another study (Gaines, 1969[2/]). Gaines states that the majority of pesticides tested by the oral route were more toxic to female than

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[1/] Hazleton, L. W., and E. G. Holland, "Toxicity of Malathion: Summary of Mammalian Investigations," AMA Arch. Ind. Hyg. Occup. Med., 8:399-405 (1953).

[2/] Gaines, T. B., "Acute Toxicity of Pesticides," Toxicol. Appl. Pharmacol., 14:515-534 (1969).

Table 10. ACUTE ORAL TOXICITY OF MALATHION TO RATS

Formulation	Measurement	Dose (mg/kg)		References
		Male	Female	
Technical 99%	Oral LD_{50}	1,845[a]		f/
Technical 98%	Oral LD_{50}	1,400[a]		g/
Technical 90%	Oral LD_{50}	480[a]		f/
Technical 99%	Oral LD_{50}	1,500[b]		h/
Technical 90%	Oral LD_{50}	390[b]		h/
Technical 90%	Oral LD_{50}	1,156[c]		f/
Technical 90%	Oral LD_{50}	940[c]		h/
Technical 65%	Oral LD_{50}	3,690[c]	739[c]	f/
Technical 95%	Oral LD_{50}	2,100[d]		h/
Technical 99%	Oral LD_{50}	1,375[e]	1,000[e]	i/, j/, k/
Lowest dose to kill an adult rat				
Technical 90%+	Oral	1,000[e]	750[e]	j/

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a/ Dissolved in corn oil.

b/ Dissolved in vegetable oil.

c/ Dissolved in propylene glycol.

d/ Undiluted.

e/ Dissolved in peanut oil.

f/ Hazelton and Holland, *op. cit.* (1953).

g/ Frawley, J. P., H. N. Fuyat, E. C. Hagan, J. R. Blake, and O. G. Fitzhugh, "Marked Potentiation in Mammalian Toxicity from Simultaneous Administration of Two Anticholinesterase Compounds," *J. Pharmacol. Exp. Ther.*, 121:96-106 (1957).

h/ Golz, H. H., and C. B. Shaffer, *Malathion: Summary of Pharmacology and Toxicology*, American Cyanamid Company, New York, 2-14 (1956 Revised).

i/ Kimmerle, G., and D. Lorke, "Toxicology of Insecticidal Organophosphates," *Pflanz.-Nachr. Bayer*, 21:111-142 (1968).

j/ Gaines, T. B., *op. cit.* (1969).

k/ "Toxic Hazards of Pesticides to Man," World Health Organization, *Tech. Rept. Ser. No. 114* (1956).

male rats. The reason for these reported differences are not clear. Young animals appear to be more susceptible to malathion than older animals (Brodeur and DuBois, 1963[1]). The dietary protein concentration also influences the acute oral toxicity of malathion. It was shown that as the amount of casein in the diet of rats is decreased, the acute toxicity is increased (Boyd, 1969[2]). Thus, much of the variation in acute LD_{50} values can be attributed to differences in experimental techniques.

The toxicity of malathion may be affected by other organophosphate compounds. Frawley et al. (1957) observed that the simultaneous administration of two organophosphate compounds produced a higher toxic effect in some instances than was to be expected, based on the known toxicity of each compound. This was a potentiation effect, and the toxicity of malathion has been shown to be influenced by other, but not all, organophosphate compounds (Kimmerle and Lorke, 1968).

Acute toxicity routes other than oral - rats - The toxicity of malathion for rats by routes of exposure other than oral is shown in Table 11.

The intraperitoneal toxicity of malathion varied with the age of the animals. The LD_{50} for adult rats was 750 and the LD_{50} for weanling rats was 340 mg/kg (Brodeur and DuBois, 1963).

Although exposure by the intraperitoneal route is of less importance than by some other route in characterizing the potential health hazard of the compound, it is important in giving information as to the inherent toxicity of the compound. The intravenous administration of malathion to rats represented the most toxic route and the subcutaneous toxicity was comparable to that of the oral. The acute intravenous and subcutaneous LD_{50} values are 50 mg/kg and 1,000 mg/kg, respectively. The dermal LD_{50} value of malathion is 4,444 mg/kg. Exposure of rats to saturated vapors of the compound caused no mortality and the only symptoms noted were labored breathing and depression (Spiller, 1961[3]).

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[1] Brodeur, J., and K. P. DuBois, "Comparison of Acute Toxicity of Anticholinesterase Insecticides to Weanling and Adult Male Rats," Proc. Soc. Exp. Med., 114(2):509-511 (1963).

[2] Boyd, E. M., "Dietary Protein and Pesticides Toxicity in Male Weanling Rats," Bull. WHO, 40:801-805 (1969).

[3] Spiller, D., "A Digest of Available Information on the Insecticide Malathion," Adv. Pest Control Res., Vol. IV, Interscience Publishers (1961).

Table 11. ACUTE TOXICITY OF MALATHION FOR RATS VIA ROUTES OTHER THAN ORAL

	Dose			
	Adults		Weanlings	
Measurement	Male	Female	Male	References
IP LD_{50} (mg/kg)	750		340	a,b/
IV LD_{50} (mg/kg)	50	50		c/
SC LD_{50} (mg/kg)	1,000			d/
D LD_{50} (mg/kg)	> 4,444	> 4,444		e,f/
LC_{50} - 1 hr (mg/ℓ)	>60	> 60		g/

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a/ Kimmerle and Lorke, *op. cit.* (1968).
b/ Brodeur and DuBois, *op. cit.* (1963).
c/ Hagan, E. C., "Acute Toxicity of 0,0-Dimethyl Dithiophosphate of Diethyl Mercaptosuccinate," *Pharmacol. Exp. Ther.*, 12:327 (1953).
d/ Spiller, *op. cit.* (1961).
e/ Gaines, *op. cit.* (1969).
f/ Anon., WHO, *op. cit.* (1956).
g/ Hazleton and Holland, *op. cit.* (1953).

Note: IP LD_{50} - Intraperitoneal exposure.
IV LD_{50} - Intravenous exposure.
SC LD_{50} - Subcutaneous exposure.
D - Dermal exposure.
LC_{50} - Lethal concentration by inhalation.

Table 12. SUBACUTE ORAL TOXICITY TEST IN RATS FED MALATHION

Concentration of malathion in feed (ppm)	Duration of test	Mortality (%)	Comments	References
100, 1,000, 5,000	33 days	0	No effects on food intake and weight gain at any level. Cholinesterase activity of erythrocytes at 100 ppm not depressed, but significantly depressed at 1,000 and 5,000 ppm.	a/
100, 500	8 weeks	0	No effects on whole blood cholinesterase activity.	b/
4,000	5 months	0	Normal growth and food consumption. No gross signs of intoxication.	c/
1,000	6 months	0	No significant findings.	d/

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a/ Golz and Shaffer, *op. cit.* (1956).
b/ Frawley et al., *op. cit.* (1957).
c/ Kalow and Marton, *op. cit.* (1961).
d/ Holland et al., *op. cit.* (1952).

Subacute oral and intraperitoneal toxicity - rats - Thirty-three day, 8 week, and 5 and 6 month subacute feeding studies were conducted with various concentrations of malathion in the feed of rats. These data are summarized in Table 12. Golz and Shaffer (1956) conducted a 33-day feeding study with rats fed diets of malathion containing 100, 1,000, and 5,000 ppm. There were no deaths during the period of feeding and no gross signs of toxicity referable to cholinesterase inhibition. There were no effects on weight gain and food intake. Cholinesterase activity of red blood cells was significantly depressed at 1,000 and 5,000 ppm, but cholinesterase activity of brain and liver was not affected. Plasma cholinesterase was inhibited only at 5,000 ppm. Frawley et al. (1957) showed that feeding rats diets containing 100 and 500 ppm malathion for 8 weeks had no effect on whole blood cholinesterase activity. Kalow and Marton (1961)[1] fed male and female rats malathion in the diet at 4,000 ppm (240 mg/kg) for 5 months. Growth was normal in these animals and no signs of intoxication occurred. However, breeding animals exposed to this dietary level of malathion exhibited a smaller average litter size than the control, and the number of young alive at 7 and 21 days was about half the number in the control group. Holland et al. (1952)[2] showed that male and female rats tolerated diets containing 1,000 ppm malathion for 6 months without any adverse effects.

DuBois et al. (1953)[3] showed that rats could tolerate 100 mg/kg daily for 60 days intraperitoneally without mortality, but that after daily doses for the same period of 200 and 300 mg/kg, the mortality rate was 60 and 100%, respectively.

Subacute inhalation toxicity - rats - Inhalation experiments were conducted with rats by Golz (1955).[4] Neither static vapor nor dynamic flows up to 5 ppm caused significant depression of cholinesterase activity. The results of investigations are summarized as follows.

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[1] Kalow, W., and A. Marton, "Second Generation Toxicity of Malathion in Rats," Nature, 192(4801):464-465 (1961).

[2] Holland, E. G., L. W. Hazleton, and D. L. Hanzal, "Toxicity of Malathion (0,0-Dimethyl Dithiophosphate of Diethyl Mercaptosuccinate)," Fed. Proc., 11:357 (1952).

[3] Dubois, K. P., J. Doull, J. Deroin, and O. K. Cummings, "Studies on the Toxicity and Mechanism of Action of Some New Insecticidal Thionophosphates," AMA Arch. Inc. Hyg. Occup. Med., 8:350-358 (1953).

[4] Golz, H. H., "Malathion: Summary of Pharmacology and Toxicology," American Cyanamid Company (1955).

Method of exposure	Duration of test	Mortality (%)	Comments
Static vapor toxicity 0.12 ppm	2 weeks	0	No significant depression of cholinesterase activity.
Dynamic flow 5 ppm	4 weeks*	0	No significant changes observed.

* Eight hours a day, 5 days a week.

Chronic oral toxicity - rats - Several investigators have administered malathion to the diets of rats at various concentrations. (See Table 13.) Hazleton and Holland (1953) fed rats malathion (technical 65% as a 25% wettable powder) in the diet at 100, 1,000 and 5,000 ppm for 2 years. There were no mortalities at any level. At 5,000 ppm, food intake and weight gain were reduced. Plasma cholinesterase, cholinesterase of RBC's and brain cholinesterase activity were reduced at both the 1,000 and 5,000 ppm levels. There were no significant gross or microscopic findings at autopsy of these rats. In another study, Hazleton and Holland (1953) fed malathion (technical 90% as a 25% wettable powder) at 100, 1,000, and 5,000 ppm for 2 years. The essential finding in this study was that the terminal cholinesterase activity in plasma, erythrocytes and brain was significantly depressed at all levels of exposure. Golz and Shaffer (1956) fed malathion (technical 99% as a 25% wettable powder) to male and female rats for 2 years at levels of 500, 1,000, 5,000 and 20,000 ppm in the diet. There was marked reduction of growth, food intake and the cholinesterase activity of brain, plasma and erythrocytes at 20,000 ppm. The cholinesterase of the erythrocytes was also markedly reduced at 500 ppm. In view of these findings a "no-effect" level of 100 ppm has been established for rats (Anon., FAO/WHO Report, 1965[1]). This is equivalent in man to 16 mg a day or 0.2 mg/kg body weight per day. The estimated ADI for man is 0 to 0.02 mg/kg body weight (Anon., FAO/WHO Report, 1965).

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[1] FAO/WHO, "Malathion," 1965 Evaluation of the Toxicity of Pesticide Residues in Food, 136-141 (1965).

Table 13. CHRONIC TOXICITY OF MALATHION TO RATS

Concentration of malathion in feed (ppm)	Duration of test (years)	Mortality (%)	Comments	References
100, 1,000, 5,000 Technical 65% as 25% wettable powder	2	0	No gross effects at 100 and 1,000 ppm. At 5,000 ppm food intake and weight gain were reduced. Significant depression of plasma, erythrocytes and brain cholinesterase activity at 1,000 and 5,000 ppm.	a,b/
100, 1,000, 5,000 Technical 90% as 25% wettable powder	2	0	Growth rate and food intake not influenced. Significant depression of cholinesterase activity at all levels of exposure.	a,b/
500, 1,000, 5,000, 20,000 Technical 99% as 25% wettable powder	2	0	Significant depression of cholinesterase activity of erythrocytes at all levels of exposure. Food intake and growth not affected at 500 and 1,000 ppm.	c/

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a/ FAO/WHO, op. cit. (1965).
b/ Hazleton and Holland, op. cit. (1953).
c/ Golz and Shaffer, op. cit. (1956).

Acute oral toxicity - mice - A summary of the acute oral toxicity of malathion to mice is shown in Table 14. The vehicle and the composition of the formulations have a considerable influence on absorption following oral administration to mice. Mice appear to be more resistant to malathion than rats. Male and female mice appear to be about equally susceptible to malathion (Hazleton and Holland 1953). The symptoms of toxicity of mice exposed to toxic doses of malathion are those due to cholinesterase inhibition. These symptoms include excessive salivation, depression and tremors. The less severe symptoms are usually of short duration and unless death occurs within several hours, recovery is rapid and apparently complete (Golz and Shaffer, 1956).

Table 14. ACUTE ORAL TOXICITY OF MALATHION TO MICE

Formulation	Measurement	Dose (mg/kg) Male	Dose (mg/kg) Female	References
Technical 99%	Oral LD_{50}	3,321		a/
Technical 90%	Oral LD_{50}	886		a/
Technical	Oral LD_{50}	930		b/
Technical	Oral LD_{50}	775		b/
Technical 90%	Oral LD_{50}	720		c/
Technical 99%	Oral LD_{50}	3,330		c/
Technical 65%	Oral LD_{50}	1,260		a/
Technical 65%	Oral LD_{50}	930	940	c/
Technical 65%	Oral LD_{50}		1,158	a/

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a/ Hazleton and Holland, op. cit. (1953).
b/ Spiller, op. cit. (1961).
c/ Golz and Shaffer, op. cit. (1956).

Acute toxicity routes other than oral - mice - The acute intraperitoneal and inhalation toxicity of mice is summarized in Table 15. A search of the literature revealed that toxicity studies by these routes of exposure were very few. The intraperitoneal toxicity to mice is reported to be 815 mg/kg (O'Brien et al., 1958[1]) and between 420 and 474 mg/kg (Hazleton and Holland, 1953).

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[1] O'Brien, R. D. G. D. Thron, and R. W. Fisher, "New Organophosphates Insecticides Developed on Rational Principles," J. Econ. Entomol., 51(5):714-718 (1958).

Table 15. ACUTE TOXICITY OF MALATHION TO MICE - ROUTES OTHER THAN ORAL

Route	LD_{50} (mg/kg) Male	Female	Mixed	References
Intraperitoneal			815	a/
Intraperitoneal			420-474	b/
Inhalation-static saturated vapors			LC_{50} 8 hr > 15 mg/m^3	c/

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a/ O'Brien, et al., *op. cit.* (1958).
b/ Hazleton and Holland, *op. cit.* (1953).
c/ Golz and Shaffer, *op. cit.* (1956).

Subacute oral and inhalation toxicity - mice - Mice have been exposed to aerosols containing 5 ppm of malathion for 8 hr a day, 5 days a week for 4 weeks. There was no significant depression of cholinesterase activity or gross pathology associated with the exposure (Golz, 1955).

Acute oral, intraperitoneal and dermal toxicity - guinea pigs - The acute oral LD_{50} in guinea pigs is reported to be 570 mg/kg (Hagan, 1953). The intraperitoneal LD_{50} for guinea pigs is reported to be 500 mg/kg (Spiller, 1961). The acute dermal (Cuff Method--24 hr exposure) LD_{50} to guinea pigs is reported to be greater than 12,300 mg/kg (Golz and Shaffer, 1956). This data is summarized in Table 16:

Table 16. ACUTE TOXICITY OF MALATHION TO GUINEA PIGS

Formulation	Route	LD_{50} (mg/kg) Male	Female	Mixed	References
--	Oral			570	a/
Technical 95%	Dermal			> 12,300	b/
--	Intraperitoneal			500	c/

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a/ Hagan, *op. cit.* (1953).
b/ Golz and Shaffer, *op. cit.* (1956).
c/ Spiller, *op. cit.* (1961).

Subacute and chronic toxicity - guinea pigs - A search of the literature failed to reveal any data on the subacute or chronic oral toxicity relative of malathion to guinea pigs.

Subacute, dermal, and inhalation toxicity - guinea pigs - In a subacute dermal experiment shown in Table 17, undiluted malathion was applied daily at a dose of 1,230 mg/kg for 4 days. Under these conditions mortality occurred (Haller and Simmons, 1952[1]).

Table 17. SUBACUTE DERMAL AND INHALATION TOXICITY OF MALATHION TO GUINEA PIGS

Route	Duration of test	Mortality (%)	Comments	References
Dermal	4 days	Mortality occurs but percent unknown.	Four daily doses of 1,230 mg/kg produces mortality.	a/
Inhalation-static vapor toxicity	2 weeks	0	No significant depression of cholinesterase activity.	b/
Inhalation-dynamic flow 5 ppm	4 weeks	0	No significant depression of cholinesterase activity or gross pathology.	b/

a/ Haller and Simmons, op. cit. (1952).
b/ Golz, op. cit. (1955).

Table 17 also summarizes the subacute inhalation toxicity of malathion to guinea pigs. As shown, there was no gross pathology or biochemical lesion associated with the exposure.

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[1] Haller, H. L., and S. W. Simmons, "Interdepartmental Committee on Pest Control," J. Econ. Entomol., 45:761-762 (1952).

Acute and chronic oral toxicity - chickens - The acute oral toxicity of malathion to chickens varies with regard to age. The LD_{50} to adult chickens was greater than 850 mg/kg (Golz and Shaffer, 1956). The LD_{50} was 370 mg/kg for chickens 2 to 3 weeks old (Sherman and Ross, 1959[1]). For chickens 3 to 4 weeks old, the LD_{50} was reported to be between 200 and 400 mg/kg, and for 1-year old chickens, the LD_{50} was reported to be between 150 and 200 mg/kg (Spiller, 1961).

Malathion levels of 250 and 2,500 ppm in the diet of male and female chickens were fed for 2 years. At the higher level, the plasma cholinesterase activity was inhibited. There were no effects on hatchability and at autopsy no gross or microscopic lesions were found (Anon., FAO/WHO Report, 1965). When chickens were fed for 15 weeks at 10,000 ppm all birds died (Frawley et al., 1956[2]).

Subacute oral and dermal toxicity - chickens - Malathion (10 ppm) was fed to day-old chicks for 2 weeks. For the following 10 weeks, the chicks were grouped and fed 10, 100, 1,000, and 5,000 ppm in their diets. No signs of toxicity were noted at doses of 100 and 1,000 ppm; growth rate and food intake were equal to that of control animals. Four animals died in the 5,000 ppm group and signs of intoxication and growth retardation were observed (Anon., FAO/WHO, 1967[3]).

When malathion as a 4% dust was worked into the feathers and skin of 10-week old hens once a week for 6 weeks, there were no deaths. Gross symptoms, food intake and weight gain were equal to controls. There was no significant inhibition of cholinesterase activity (Golz and Shaffer, 1956).

Acute, subacute and chronic toxicity - dogs - The acute intraperitoneal LD_{50} of a 95% solution of malathion to dogs is reported to be 1.51 ml/kg (Guiti and Sadeghi, 1969[4]), and the acute intravenous LD_{50} is reported to be greater than 430 mg/kg but less than 600 mg/kg (Bagdon and DuBois, 1955[5]).

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[1] Sherman, M., and E. Ross, "Toxicity of House Fly Larvae to Insecticides Administered as Single Oral Dosages to Chicks," J. Econ. Entomol., 52(4):719-723 (1959).

[2] Frawley, J. P., R. E. Zwickey, and H. N. Fuyat, "Myelin Degeneration in Chickens with Subacute Administration of Organic Phosphorus Insecticides," Fed. Proc., 15:424 (1956).

[3] FAO/WHO, "Malathion," 1966 Evaluation of Some Pesticide Residues in Food, Geneva, 172-185 (1967).

[4] Guiti, N., and D. J. Sadeghi, "Acute Toxicity of Malathion in the Mongrel Dog," Toxicol. Appl. Pharmacol., 15(1):244-245 (1969).

[5] Bagdon, R. E., and K. P. DuBois, "Pharmacologic Effects of Chlorthion, Malathion and Tetrapropyl Dithionopyrophosphate in Mammals," Arch. Int. Pharmacodyn. Ther., 103:192-199 (1955).

In a subacute inhalation study one dog was exposed to an aerosol concentration of malathion of 5 ppm daily for 4 weeks. The erythrocyte and plasma cholinesterases were reduced to 34% and 52% of normal, respectively (Anon., FAO/WHO Report, 1965).

No information could be found concerning long-term studies in dogs.

Acute, subacute and chronic toxicity - cats - A search of the literature revealed that very little work has been initiated using cats as the animal species with regard to malathion toxicity. Cats were reported to have survived an acute oral dose of 500 mg malathion. Cats were powdered daily for 14 days with 25% dust and dipped in 0.22% emulsion without harmful effects (Spiller, 1961). Some additional information appears in the behavioral effects subsection.

Acute, subacute and chronic toxicity - rabbits - The acute oral LD_{50} for rabbits is reported to be greater than 900 mg/kg (Adkins et al., 1955[1]).

The acute dermal LD_{50} to rabbits is reported to be between 2,460 and 6,150 mg/kg (Haller and Simmons, 1952).

Rabbits are not the animal of choice for subacute and chronic studies; therefore, no information was found for these types of studies in rabbits.

Toxicity to Domestic Animals -

Goats - Goats were exposed dermally to malathion as 0.1% and 0.25% dip solutions without any harmful effects (Golz and Shaffer, 1956).

Sheep - The acute oral LD_{50} of malathion to sheep was reported to be less than 150 mg/kg (Radeleff and Woodard, 1957[2]). The maximum safe oral dose (MSD) to sheep is reported to be 50 mg/kg, and the minimum toxic dose (MTD) is 100 mg/kg (Wilber, 1960[3]).

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[1] Adkins, T. R., Jr., W. L. Sowell, and F. S. Arant, "Systemic Effect of Selected Chemicals on the Bed Bug and Lone Star Tick When Administered to Rabbits," J. Econ. Entomol., 48:139-141 (1955).

[2] Radeleff, R. D., and G. T. Woodard, "The Toxicity of Organic Phosphorus Insecticides to Livestock," J. Am. Vet. Med. Assoc., 130: 215-216 (1957).

[3] Wilber, C. G., "New Insecticides. Toxicity, Hazards, and Therapy," Iowa State Univ. Vet., 23:21-23 (1960).

Cattle - The LD_{50} of malathion (95% technical) to male dairy calves is 80 mg/kg and to dairy cows is 560 mg/kg (Golz and Shaffer, 1956). In other acute LD_{50} toxicity studies, the oral LD_{50} value in cattle has been reported to be less than 200 mg/kg (Radeleff and Woodard, 1957). When beef cattle were exposed to a 0.5% spray once a week for 16 weeks, no gross evidence of toxicity was observed; however, red blood cell cholinesterase activity was depressed. Exposure of dairy cattle to 1% emulsion or to a 0.5% suspension once a week for 2 weeks produced neither gross symptoms of toxicity nor depression of cholinesterase activity. Exposure of cows and calves to a 1.25% spray for 7 weeks with a total of six applications, caused depression of cholinesterase activity (Golz and Shaffer, 1956).

The minimum toxic dose (MTD) of malathion to baby calves was between 10 and 20 mg/kg (Radeleff et al., 1955[1]).

Symptomatology and Pathology Associated with Mammals - The symptoms of poisoning caused by malathion in mammals are those characteristic of cholinesterase inhibition. The intensity, time of appearance, and duration of symptoms depend upon the dose and method of application. High doses result in systemic poisoning and the initial manifestations include both muscarinic effects such as anorexia, nausea, sweating, vomiting, diarrhea, salivation, bradycardia, profuse perspiration, pallor, dyspnea, and nicotinic effects such as muscle twitching and muscle spasm.

Central nervous system symptoms consist initially of restlessness, discomfort, tremors, confusion, and, later, coma. Respiratory depression is an important cause of death (Kimmerle and Lorke, 1968). Brain, plasma and erythrocyte cholinesterase are maximally inhibited in rats during the first 24 hours. Plasma and brain levels returned to normal after 12 days and the red blood cells after 28 days following intraperitoneal injection (Hazleton and Holland, 1953).

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[1] Radeleff, R. D., G. T. Woodard, W. J. Nickerson, and R. C. Bushland, "Part II. Organic Phosphorus Insecticides," The Acute Toxicity of Chlorinated Hydrocarbon and Organic Phosphorus Insecticides to Livestock, USDA Tech. Bull. No. 1122, 36-46 (1955).

Summary - The acute toxicity of malathion for the rat is summarized in the following table:

Acute Toxicity of Malathion in the Rat by Various Routes of Administration

Route of entry	Measurement	Value	
		Male	Female
Oral	LD_{50} (mg/kg)	1,375-1,845	1,000
Intraperitoneal	LD_{50} (mg/kg)	750	
Intravenous	LD_{50} (mg/kg)	50	50
Subcutaneous	LD_{50} (mg/kg)	1,000	--
Dermal	LD_{50} (mg/kg)	> 4,444	> 4,444
Inhalation	LC_{50} 1 hr (mg/ℓ)	> 60	> 60

Rats have been fed 5,000 ppm of malathion for 33 days without lethality or any other sign indicating gross toxicity, although blood cholinesterase was depressed. Red blood cell cholinesterase was depressed where 1,000 ppm were fed to rats for 6 months. Other signs of toxicity were not observed.

Rats have been fed 100, 1,000, and 5,000 ppm of malathion (technical 65%, as a 25% wettable powder) for 2 years. There was no mortality at any level. Body weight gain was reduced at 5,000 ppm and the blood cholinesterase levels were significantly reduced at 1,000 and 5,000 ppm levels.

In another chronic study 500, 1,000, 5,000 and 20,000 ppm of malathion (technical 99% as a 25% wettable powder) was fed to rats for 2 years. There were marked effects (reduced growth and food intake, and blood cholinesterase activity) at the 20,000 ppm dosage.

A "no effect" level of 100 ppm has been established for rats.

The acute oral LD_{50} values for malathion in mice ranges from 720 mg/kg to 3,321 mg/kg. The acute intraperitoneal LD_{50} value ranged from 420 to 815 mg/kg.

There were significant depressions of cholinesterase activity when mice were exposed to 5 ppm of malathion for 8 hr a day, 5 days a week for 4 weeks in an inhalation chamber.

The acute oral and intraperitoneal LD_{50} values for guinea pigs are 570 mg/kg and 500 mg/kg, respectively. The dermal LD_{50} for guinea pigs appears to be greater than 12,300 mg/kg.

The toxicity (LD_{50}) of malathion to chickens appears to vary with age of the chicken. However, the data are not consistent. (Adults - 800 mg/kg, 1-year old chickens - 150 to 200 mg/kg, 2 to 3 weeks old, 370 mg/kg.)

Malathion levels of 250 and 2,500 ppm have been fed to chickens for 2 years. There was no effect on hatchability of eggs nor were gross or microscopic lesions found. In subacute studies, chickens were fed 10, 100, 1,000 and 5,000 ppm of malathion from 2 through 12 weeks. No toxic symptoms were noted at the lower doses. Four chickens died on the 5,000 ppm.

The acute oral LD_{50} value for malathion in dogs is 1.51 ml/kg of a 95% solution of malathion. RBC and plasma cholinesterase activity was depressed 66% and 47%, respectively, when dogs were exposed to aerosol concentration of 5 ppm daily for 4 weeks.

Cats have been reported to survive an acute oral dose of 500 mg of malathion.

The acute oral LD_{50} for rabbits appears to be above 900 mg/kg.

The acute oral LD_{50} for sheep has been reported to be less than 150 mg/kg. The minimum toxic dose is 100 mg/kg.

LD_{50} values have been reported to be 560 mg/kg for dairy cows and less than 200 mg/kg for cattle. Dairy calves appear to have an LD_{50} of 80 mg/kg; the minimum toxic dose has been set between 10 and 20 mg/kg.

The symptoms of malathion poisoning are characteristic of the organophosphate compounds. These symptoms include anorexia, nausea, sweating, vomiting, diarrhea, salivation, bronchocardia, profuse perspiration, pallor, tremors and coma.

Metabolism of Malathion

Absorption - Malathion is rapidly absorbed from the gut (Anon., FAO/WHO Report, 1967). Shah and Guthrie (1970)[1] demonstrated that some malathion penetrated mouse gut and some was bound to the gut wall. The absorption occurred via passive transport and was not related to its oil/water coefficient. These same authors (1973)[1] found that malathion gut penetration in the mouse was greater in the colon, less in the rectum and least in the small intestine. Absorption of malathion through the skin and feathers of birds is slight (March et al., 1956a[2]).

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[1] Shah, A. H., and F. E. Guthrie, "Penetration of Insecticides Through the Isolated Midgut of Insects and Mammals," Comp. Gen. Pharmacol., 1:391-399 (1970).

Distribution - Pasarela et al. (1962)[3] could not detect malathion in livers, blood, kidneys, hearts, muscle or fat of calves fed 200 ppm malathion for 41-44 days. There was a small amount (less than 1 ppm) in the livers of calves sacrificed after 14 days exposure. Malathion was detected in milk of cows after exposure to 800 ppm in the feed. Claborn et al. (1956)[4] sprayed cattle with 0.5 to 1.0% malathion and found 0.08 to 0.36 ppm of malathion in the milk 5 hr later. Only traces of malathion were detected in the milk at 24 hr and none at 3 or 7 days later. No malathion was detected in the body fat 1 week after 16 sprayings with 0.5% malathion. O'Brien et al. (1961)[5] reported 0.11 ppm of some unidentified metabolite in cows' milk after ingestion of malathion. March et al. (1956b)[6] found that heifer calves sprayed twice with 1 pint of 0.5% malathion had tissue concentrations of ^{32}P ranging from 0.05 to 0.20 µg ^{32}P/g of tissue 1 to 2 weeks later. Exceptions were liver (1.2 to 0.99 µg ^{32}P/g), bone (1.37 to 1.91 µg ^{32}P/g), and hide (3.24 to 18.5 µg ^{32}P/g).

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[1] Shah, P. V., and F. E. Guthrie, "Penetration of Insecticides Through Isolated Sections of the Mouse Digestive System: Effects of Age and Region of Intestine," Toxicol. Appl. Pharmacol., 25:621-624 (1973).

[2] March, R. B., T. R. Fukuto, R. L. Metcalf, and M. G. Maxon, "Fate of ^{32}P-Labeled Malathion in the Laying Hen, White Mouse, and American Cockroach," J. Econ. Entomol., 49:185-195 (1956a).

[3] Pasarela, N. R., R. G. Brown, and C. B. Shaffer, "Feeding of Malathion to Cattle: Residue Analyses of Milk and Tissue," J. Agr. Food Chem., 10(1):7-9 (1962).

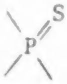
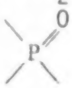
[4] Claborn, H. V., R. D. Radeleff, H. F. Beckman, and G. T. Woodard, "Malathion in Milk and Fat From Sprayed Cattle," J. Agr. Food Chem., 4(11):941-942 (1956).

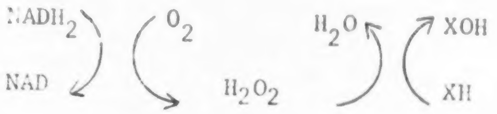
[5] O'Brien, R. D., W. C. Dauterman, and R. P. Niedermeier, "The Metabolism of Orally Administered Malathion by a Lactating Cow," J. Agr. Food Chem., 9:39-42 (1961).

[6] March, R. B., R. L. Metcalf, T. R. Fukuto, and F. A. Gunther, "Fate of ^{32}P-Labeled Malathion Sprayed on Jersey Heifer Calves," J. Econ. Entomol., 49:679-682 (1956b).

Excretion - O'Brien et al. (1961) reported that 90% of a ^{32}P-malathion dose excreted by lactating cows was found in the urine. The principal fecal metabolite was dimethyl phosphate. However, 23% of the dose was not recovered over a 3-week period. In 1967, O'Brien reported that the urinary excretion of malathion metabolites consisted of 7% desmethyl malathion in the cow, 11% in the rat and 21% in the dog. Other principal urinary metabolites were malathion mono- and di-acids. These were 63 and 17% in the cow, 12 and 48% in the rat, and 40 and 21% in the dog. The excretion of malathion has been reviewed (Anon., FAO/WHO Report, 1967). In addition to the above information it was reported that the malathion mono-acid was excreted early during the post-treatment period while the di-acid appeared later in the observation period. In feces, 85% of the labeled material excreted was malathion, 12% was malaoxon.

Biotransformation -

Activation - Metcalf and March (1953)[1] demonstrated that activation of malathion was necessary for inhibition of acetylcholinesterase activity. DuBois and Kinoshita (1968)[2] demonstrated that the activation reaction was a desulfuration of malathion and conversion to malaoxon. Earlier O'Brien (1957)[3] had shown that mouse liver microsomes could convert malathion to malaoxon and that NADH, Mg++ and nicotinamide were required. Later O'Brien (1967)[4] reported that the activation reaction (conversion of malathion to malaoxon) by microsomes required $NADH_2$ or $NADPH_2$, Mg++ and nicotinamide for the conversion of  to  . He also postulated a peroxide intermediate for the metabolic conversion according to the following scheme:



1/ Metcalf, R. L., and R. B. March, "Further Studies on the Mode of Action of Organic Thionophosphate Insecticides," Ann. Entomol. Soc. Amer., 46:63-74 (1953).

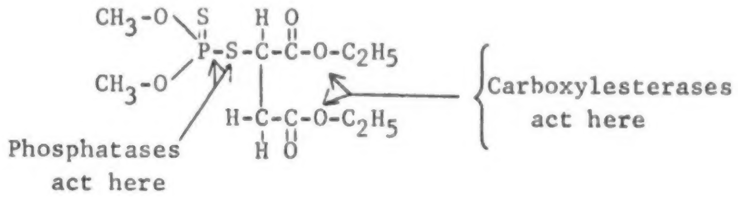
2/ DuBois, K. P., and F. K. Kinoshita, "Influence of Induction of Hepatic Microsomal Enzymes by Phenobarbital on Toxicity of Organic Phosphate Insecticides," Proc. Soc. Exp. Biol. Med., 129:699-702 (1968).

3/ O'Brien, R. D., "Properties and Metabolism in the Cockroach and Mouse of Malathion and Malaoxon," J. Econ. Entomol., 50(2): 159-164 (1957).

4/ O'Brien, R. D., Insecticides: Action and Metabolism, Academic Press, New York (1967).

While direct evidence was lacking for a role of peroxide in malathion metabolism, it has been shown that $NADH_2$ and liver microsomes do produce H_2O_2.

Degradation - Krueger and O'Brien (1959)[1] found seven metabolites of malathion in the mouse, using ion exchange chromatography. The mouse detoxified 70 to 80% of a dose in 1/2 hr. The metabolites were 68% malathion monoester, 20.5% phosphatase products and 11.5% unknown (mostly in one ion exchange peak). The site of enzyme activity is shown below:



Cohen and Murphy (1972)[2] found that only half of a malaoxon dose was detoxified by the carboxylesterase pathway and suggested that malathion may also act at some noncritical binding sites. O'Brien (1957) reported earlier that hydrolysis of malaoxon was vigorous in liver, kidney and lung. Hydrolyzing activity was greater with malathion than malaoxon. Cook and Yip (1958)[3] found that the degradation of malathion was different than many other organophosphates in that it was acted upon by carboxylesterases. Yip and Cook (1959)[4] reported that malathion-hydrolyzing enzymes had the greatest affinity for triesters, less for diesters and least for monoesters. DFP was also hydrolyzed by this system, indicating the presence of at least two esterases. O'Brien (1967) reported that the most common hydrolysis is by phosphatases. However, the phosphatases that hydrolyze malathion are different from both acid and alkaline phosphatases. Hydrolysis also accounts for some demethylation of malathion. Mammals and insects were both reported to convert malathion to the monoacid (O'Brien, 1967), but insects also produce dimethyl phosphorothioate as a metabolite.

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[1] Krueger, H. R., and R. D. O'Brien, "Relationship Between Metabolism and Differential Toxicity of Malathion in Insects and Mice," J. Econ. Entomol., 52:1063-1067 (1959).

[2] Cohen, S. D., and S. D. Murphy, "Inactivation of Malaoxon by Mouse Liver," Proc. Soc. Exp. Biol. Med., 139(4):1385-1389 (1972).

[3] Cook, J. W., and G. Yip, "Malathionase. II. Identity of a Malathion Metabolite," J. Assoc. Off. Agr. Chem., 41:407-411 (1958).

[4] Yip, G., and J. W. Cook, "Malathionase. III. Substrate Specificity Studies," J. Assoc. Off. Agr. Chem., 42:405-407 (1959).

Chiu et al. (1968)[1] substituted the succinate in malathion and malaoxon with malonate, α-glutarate and β-glutarate. All were metabolized by liver carboxylesterase, in vitro. Earlier O'Brien et al. (1958) had suggested utilizing carboxylesterase activity in various species to design organophosphates with a selective toxicity. Hassan and Dautermann (1968)[2] found that the d-isomer of malathion was more toxic to mice than the l-isomer. Dautermann and Main (1966)[3] tested several alkoxy analogues of malathion and found that carboxylesterases were important in both malathion and malaoxon detoxification. Dahm et al. (1962)[4] using rat liver preparations, found that malaoxon degradation rates exceeded the activation rate so that little cholinesterase inhibiting activity resulted in the reaction media. Brodeur and DuBois (1963) and (1964)[5] demonstrated that weanling rats were more susceptible to malathion toxicity than adults, and adult females were more susceptible than adult males. However, testosterone pretreatment decreased the toxicity of malathion in weanlings, females and castrated males. Castrated males were as susceptible as females. Malathion toxicity did not decrease with maturation of castrated weanlings. Pretreatment of rats with estradiol increased malathion toxicity in all animals. Stevens et al. (1972)[6] reported that malathion given 1 hr before hexabarbital increased sleeping time due to inhibition of hexabarbital metabolism. It also depressed ethylmorphine and aniline metabolism. Later, Stevens and Greene (1973)[1] found that the inhibition of ethylmorphine metabolism by malathion, *in vitro*, was not correlated with NADPH oxidation, cytochrome c reduction or cytochrome P-450 reduction. There was a relationship between the inhibition of ethylmorphine metabolism by malathion and malaoxon and the binding affinity of these agents to cytochrome P-450 obtained from rats pretreated with bis-*p*-nitrophenyl phosphate.

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[1] Chiu, Y. C., A. Hassan, F. E. Guthrie, and W. C. Dauterman, "Studies on a Series of Branched-Chain Analogs of Diethyl Malathion and Malaoxon with Regard to Toxicity and *in vitro* Enzymatic Reactions," *Toxicol. Appl. Pharmacol.*, 12:219-228 (1968).

[2] Hassan, A., and W. C. Dauterman, "Studies on the Optically Active Isomers of O,O-Diethyl Malathion and O,O-Diethyl Malaoxon," *Biochem, Pharmacol.*, 17:1431-1439 (1968).

[3] Dauterman, W. C., and A. R. Main, "Relationship Between Acute Toxicity and *in vitro* Inhibition and Hydrolysis of a Series of Carbalkoxy Homologs of Malathion," *Toxicol. Appl. Pharmacol.*, 9:408-418 (1966).

[4] Dahm, P. A., B. E. Kopecky, and C. B. Walker, "Activation of Organophosphorus Insecticides by Rat Liver Microsomes," *Toxicol. Appl. Pharmacol.*, 4:683-696 (1962).

[5] Brodeur, J., and K. P. DuBois, "Ali-Esterase Activity and Sex Difference in Malathion Toxicity," *Fed. Proc.*, 23(2):200 (1964).

[6] Stevens, J. T., R. E. Stitzel, and J. J. McPhillips, "Effects of Anticholinesterase Insecticides of Hepatic Microsomal Metabolism," *J. Pharmacol. Exp. Ther.*, 181(3):576-583 (1972).

Ruminants may be protected to some degree from the oral toxicity of malathion by rumen fluid, since Cook (1957)[2] showed that this destroys malathion *in vitro*. Schwartz et al. (1973)[3] found that malathion did not affect rumen microbial function.

Potentiation - In 1957, Frawley et al. reported that the simultaneous administration of EPN (O-Ethyl-O-p-nitrophenyl phenylphosphorothioate) and malathion to dogs resulted in a 50-fold increase in malathion toxicity. This effect was less pronounced in rats. Further studies demonstrated that this was not the result of a chemical interaction but a chemical-biological action. Murphy and DuBois (1957)[4] found that EPN inhibited the enzyme which detoxified malathion both *in vivo* and *in vitro*. The highest enzyme concentration was in the liver, but some activity occurred in serum, kidney and lung. At about the same time, Cook et al. (1957) postulated that EPN inhibited esterase cleavage of malathion as a mechanism of potentiation. DuBois (1958)[5] pointed out the potential hazards associated with possible pesticide-drug interaction-potentiation.

Knaak and O'Brien (1960)[6] reported that carboxylesterases are inhibited by EPN both *in vivo* and *in vitro*.

1/ Stevens, J. T., and F. E. Greene, "Response of the Mixed Function Oxidase System of Rat Hepatic Microsomes to Parathion and Malathion and Their Oxygenated Analogs," *Life Sci.*, 13:1677-1691 (1973).

2/ Cook, J. W., "*In vitro* Destruction of Some Organophosphate Pesticides by Bovine Rumen Fluid," *J. Agr. Food Chem.*, 5(11):859-863

3/ Schwartz, C. C., J. G. Nagy, and C. L. Streeter, *J. Anim. Sci.*, 37(3): 821-826 (1973).

4/ Murphy, S., and K. DuBois, "Quantitative Measurement of Inhibition of the Enzymatic Detoxification of Malathion by EPN (Ethyl-p-nitrophenyl Thiobenzenephosphonate)," *Proc. Soc. Exp. Biol. Med.*, 96(3): 813-818 (1957).

5/ DuBois, K. P., "Potentiation of the Toxicity of Insecticidal Organic Phosphates," *AMA Arch. Ind. Health*, 19:488-496 (1958).

6/ Knaak, J. B., and R. D. O'Brien, "Effect of EPN on *in vivo* Metabolism of Malathion by the Rat and Dog," *J. Agr. Food Chem.*, 8:198-203 (1960).

Main and Braid (1962)[1] partially purified rat and human liver aliesterases and found that they converted 1 mole of malathion to 1 mole of malathion monoacid. They found that rat serum had some aliesterase activity but human blood had none. Rat aliesterases, but not cholinesterases, were totally inhibited by tri-O-tolyl phosphate (TOTP). They also found that TOTP increased malathion toxicity almost 100-fold. They concluded that aliesterases govern malathion toxicity and their inhibition was largely responsible for potentiation by other organophosphates. Brodeur and DuBois (1964) demonstrated that malathion was hydrolyzed mainly by rat liver aliesterases. Pretreatment of animals with phenobarbital decreased the toxicity of malathion by stimulating liver aliesterases. TOTP abolished this reduced toxicity brought about by phenobarbital. Sex differences in the acute toxicity of malathion appears to be closely related to unequal levels of aliesterases in the livers of male and female rats; stimulation of liver enzymes in females abolishes this sex difference in malathion toxicity.

Keplinger and Deichmann (1967)[2] reported some potentiation of malathion with chlordane plus parathion. However, they found an antagonism between malathion and aldrin or DDT.

Cohen and Murphy (1971)[3] reported that EPN potentiation was more closely associated with inhibition of triacetin esterases than diethylsuccinate, methyl butyrate or malathion esterases. Treatment with 5 mg/kg parathion inhibited diethylsuccinate, triacetin and methylbutyrate esterases 75% but did not potentiate malathion toxicity. They presented evidence that carboxylesterase inhibition is not sufficient to predict potentiation. Later, Cohen et al. (1972)[4] found that TOTP inhibited carboxylesterase activity, but further TOTP increased inhibition of liver binding of malaoxon and increased acetylcholinesterase inhibition. They concluded that potentiation may be by multiple mechanisms rather than a single inhibitory process. A further discussion of TOTP and potentiation of malathion has been presented by DuBois (1972).[1]

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[1] Main, A. R., and P. E. Braid, "Hydrolysis of Malathion by Ali-Esterases *in vitro* and *in vivo*," *Biochem. J.*, 84:255-263 (1962).

[2] Keplinger, M. L., and W. B. Deichmann, "Acute Toxicity of Combinations of Pesticides," *Toxicol. Appl. Pharmacol.*, 10:586-595 (1967).

[3] Cohen, S. D., and S. D. Murphy, "Carboxylesterase Inhibition as an Indicator of Malathion Potentiation in Mice," *J. Pharmacol. Exp. Ther.*, 176(3):733-742 (1971).

[4] Cohen, S. D., J. E. Callaghan, and S. D. Murphy, "Investigation of Multiple Mechanisms for Potentiation of Malaoxon's Anticholinesterase Action by Triorthotolyl Phosphate," *Proc. Soc. Exp. Biol. Med.*, 141(3):906-910 (1972).

Miscellaneous reactions - O'Brien (1956)[2] reported that malathion not only inhibited cholinesterase but also succinoxidase. Murphy (1966)[3] found an increase in rat liver alkaline phosphatase and tyrosine-α-ketoglutarate transaminase after malathion poisoning. This was thought to be mediated through adrenal function since a similar response was obtained with injected glucocorticoids. Murphy et al. (1968)[4] found that malathion was a poor inhibitor of brain cholinesterase, *in vitro*, but malaoxon was a good inhibitor. Feland and Smith (1972)[5] found a decrease in liver hexosamine and a decrease in $^{35}SO_4$ uptake after malathion treatment, indicating a loss of mitochondrial mucopolysaccharide. A decrease in mitochondrial swelling confirmed membrane damage. Ramu and Drexler (1973)[6] induced hyperglycemia in fasted rats with toxic doses of malathion. This was prevented by atropine but not by pretreatment with reserpine or ganglion blockade.

Tissue Accumulation - There is no evidence for long-term accumulation of malathion or malaoxon in the tissues (Pasarela et al., 1962; Claborn et al., 1956; O'Brien et al., 1961; March et al., 1956a and b).

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[1] DuBois, K. P., "The Interaction of Environmental Chemicals With Drugs," *Drug Info. J.*, 6(1):53-58 (1972).

[2] O'Brien, R. D., "The Inhibition of Cholinesterase and Succinoxidase by Malathion and Its Isomer," *J. Econ. Entomol.*, 49(4):484-490 (1956).

[3] Murphy, S. D., "Response of Adaptive Rat Liver Enzymes to Acute Poisoning by Organophosphate Insecticides," *Toxicol. Appl. Pharmacol.*, 8:266-276 (1966).

[4] Murphy, S. D., R. R. Lauwerys, and K. L. Cheever, "Comparative Anticholinesterase Action of Organophosphorus Insecticides in Vertebrates," *Toxicol. Appl. Pharmacol.*, 12:22-35 (1968).

[5] Feland, B., and J. T. Smith, "Malathion Intoxication and Mitochondrial Damage," *J. Agr. Food Chem.*, 20(6):1274-1275 (1972).

[6] Ramu, A., and H. Drexler, "Hyperglycemia in Acute Malathion Intoxication in Rats," *Isr. J. Med. Sci.*, 9(5):635-639 (1973).

Summary

1. Malathion is readily absorbed from the gastrointestinal tract by passive transport, and poorly absorbed from skin.
2. Very low concentrations of malathion are widely distributed in tissues. Concentrations in liver and bone are somewhat higher.
3. Malathion metabolites are mostly excreted in urine. In mammals these urinary metabolites are mainly mono- and di-acids of malathion.
4. Malathion requires activation for anticholinesterase activity by conversion from the thiol to its oxygen analogue.
5. Activation is at the microsomal level and requires $NADH_2$, Mg++ and nicotinamide.
6. Malathion is degraded by phosphatases and carboxylesterases or aliesterases.
7. Malathion toxicity is potentiated by EPN, TOTP and possibly some other organophosphates. Potentiation has been postulated to be mediated via carboxylesterase or aliesterase inhibition, but the mechanism is not fully understood. Some evidence indicates that potentiation may be via multiple mechanisms.

Effects on Reproduction

The effects of malathion on reproduction in laboratory animals, avian species and domestic animals are reviewed in the following paragraphs.

Laboratory Animals - Rats have been fed a diet that contained 4,000 mg of malathion per kilogram of diet. The daily intake approximated 240 mg/kg of body weight of malathion (Kalow and Marton, 1961). The number of newborn rats that were alive at 7 days was 105 for the controls and 56 for the treated animals. The number of newborn alive at weaning (21 days) for the controls was 75, and 34 for the treated animals. Nine weeks after birth the average body weight for the controls was 152 g and the body weight of the treated rats was 136 g. The retardation of the treated group was significant at the 1% level.

Avian Species - Ross and Sherman (1960)[1] investigated the effects of feeding malathion on growth and egg production. The malathion was incorporated in the feed of chickens at 100 mg/lb of feed for the first 4 weeks, followed by an increase to 200 mg/lb from the 5th to the 7th week, and up to 500 mg/lb through the 8th to the 29th week. The birds consuming malathion showed a lower weight gain compared to the controls, and during the test period there was a 25% mortality of the birds consuming malathion. The inclusion of the test amounts of malathion did not significantly reduce egg production.

Marliac and Mutchler (1963)[2] injected eggs with 50 mg of malathion and produced chicks with bleached feathers and slightly shortened legs. Chicks hatched from eggs injected with 1 mg of EPN had no apparent limb malformations, but showed varying degrees of paralysis. When 25 mg of malathion and 0.5 mg of EPN were combined in an injection, a decrease in hatchability resulted, along with severely deformed legs, parrot beak, and feather inhibition in most cases.

Dunachie and Fletcher (1969)[3] conducted a study of the effect of injection of insecticides on the hatchability of hen eggs. They reported that the hatchability of eggs injected with 25, 100, 200, 300, 400, and 500 ppm of malathion dissolved in acetone was 85, 87, 62, 71, 42 and 6%, respectively. When the eggs were injected with 50, 100, and 200 ppm of malathion dissolved in corn oil, the hatchability was 84, 9, and 9%.

Dunachie and Fletcher (1969) also showed that injection of malathion in combination with Ethion (25/75,* 75/25), Mercarbam (25/75, 50/50), Trichlorphon (25/75), and Morphothion (25/75, 75/25) brought about an enhanced depressant effect on hatchability of hen eggs.

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[1] Ross, E., and M. Sherman, "The Effect of Selected Insecticides on Growth and Egg Production When Administered Continuously in the Feed," Poult. Sci., 39:1023-1311 (1960).

[2] Marliac, J. P., and M. K. Mutchler, "Use of the Chick Embryo Technique for Detecting Potentiating Effects of Chemicals," Fed. Proc., 22:188 (1963).

[3] Dunachie, J. F., and W. W. Fletcher, "An Investigation of the Toxicity of Insecticides to Birds' Eggs Using the Egg-Injection Technique," Ann. Appl. Bio., 64(3):409-423 (1969).

* 25/75 indicates 25 ppm malathion with 75 ppm Ethion, etc.

Sauter and Steele (1972)[1] fed malathion to chickens at 0.1, 1.0 and 10.0 ppm malathion (5% wettable powder). The fertility of the eggs from chickens treated with these levels of malathion was not affected. However, the hatchability of fertile eggs was reduced at the 1 ppm level from 94.14% (control) to 85.4%, and the 10 ppm level forced this value down to 81.6%. It appeared that egg production was somewhat depressed by 0.1, 1.0 and 10.0 ppm malathion. There was some effect on embryonic death (5% increase over controls for the 1.0 ppm and the 10 ppm malathion treated birds).

Hill et al. (1971)[2] investigated the effects of ultralow volume applications of malathion in mosquito control in Hale County, Texas, with emphasis of the study being on the effect on nontarget animals. The amount of malathion used was 3 fl oz/acre. Nine sprays were conducted over the City of Plainview, Texas. The effect of spraying on house sparrows was selected for observation because of their density and commensal relationship with man. The weekly avian total population increased during the summer. No decline was indicated that might be in any way related to the spraying operation. No indications were evident in the house sparrows' population of anomalies in mating, nesting, or aggressiveness.

Domestic Animals - Beck (1953)[3] made a study of a number of insecticides on the metabolism and motility of boar spermatozoa. He evaluated the effect of these compounds on respiration, glycolysis, and motility. The presence of malathion had little, if any, effect on any of the parameters. If there was a perceptible effect, it was that the action of malathion on sperm mortality when exposed for 120 min, reduced the population to a level of nonmotility. It was postulated that the insecticide inhibited motility by altering the permeability of the cell membrane.

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[1] Sauter, E. A., and E. E. Steele, "The Effect of Low Level Pesticide Feeding on the Fertility and Hatchability of Chicken Eggs," Poult. Sci., 51:71-76 (1972).

[2] Hill, E. F., D. A. Eliason, and J. W. Kilpatrick, "Effects of Ultra-Low Volume Applications of Malathion in Hale County, Texas. III. Effect on Nontarget Animals," J. Med. Entomol., 8(2):173-179 (1971).

[3] Beck, S. D., "Effect of Insecticides on the Metabolism and Motility of Mammalian Spermatozoa," J. Econ. Entomol., 46:570-574 (1953).

Teratogenic Effects

Mammals - Kimbrough and Gaines (1968)[1] studied the effect of intraperitoneally injected malathion on the rat fetus. The highest nonfatal dosage level (900 mg/kg of body weight) was chosen for the reproduction studies and 12 female rats were divided into two groups of six for each dosage level (600 and 900 mg/kg) of each compound. On day 11 after insemination, the pregnant rats were given a single intraperitoneal injection of malathion. They found no significant difference between the malathion treated females and the controls, relative to dead fetuses per litter, resorptions, average weight of fetuses, average weight of placenta or malformations of the fetuses. They suggested that feeding studies rather than intraperitoneal injections were a more practical approach to establishing teratogenic effects for compounds since human exposure would most likely occur this way.

Avian Embryotoxicity - There have been a number of investigations of the effects of malathion as related to embryo development (Walker, 1967; Walker, 1968; Khera and Lyon, 1968; Upshall et al., 1968; Roger et al., 1969; Dunachie and Fletcher, 1969; Walker, 1971; Sauter and Steele, 1972; Ho and Gibson, 1972[2-8]).

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[1] Kimbrough, R. D., and T. P. Gaines, "Effect of Organic Phosphorus Compounds and Alkylating Agents on the Rat Fetus," Arch. Environ. Health, 16:805-808 (1968).

[2] Walker, N. E., "Distribution of Chemicals Injected into Fertile Eggs and Its Effect Upon Apparent Toxicity," Toxicol. Appl. Pharmacol., 10:290-299 (1967).

[3] Walker, N. E., "Use of Yolk-Chemical Mixtures to Replace Hen Egg Yolk in Toxicity and Teratogenicity Studies," Toxicol. Appl. Pharmacol., 12:94-104 (1968).

[4] Khera, K. S., and D. A. Lyon, "Chick and Duck Embryos in the Evaluation of Pesticide Toxicity," Toxicol. Appl. Pharmacol., 13: 1-15 (1968).

[5] Upshall, D. G., J. C. Roger, and J. E. Casida, "Biochemical Studies in the Teratogenic Action of Bidrin and Other Neuroactive Agents in Developing Hen Eggs," Biochem. Pharmacol., 17:1529-1542 (1968).

[6] Roger, J. C., D. G. Upshall, and J. E. Casida, "Structure-Activity and Metabolism Studies on Organophosphate Teratogens and Their Alleviating Agents in Developing Hen Eggs With Special Emphasis on Bidrin," Biochem. Pharmacol., 18(2):373-392 (1969).

[7] Walker, N. E., "The Effect of Malathion and Malaoxon on Esterases and Gross Development of the Chick Embryo," Toxicol. Appl. Pharmacol., 19:590-601 (1971).

[8] Ho, M., and M. A. Gibson, "A Histochemical Study of the Developing Tibiotarsus in Malathion-Treated Chick Embryos," Can. J. Zool., 50(10):1293-1297 (1972).

Walker (1967) became interested in the distribution of chemicals injected into fertile eggs and their effects upon toxicity. He reviewed some observations made by McLaughlin et al. (1963)[1] who obtained a 60% hatchability and chickens with leg and feather abnormalities when 0.05 ml of malathion (62 mg) was injected into fertile eggs prior to incubation. These facts coupled with a report by Greenwood (Anon., 1966[2]), that 5 mg of malathion suspended in corn oil reduced the hatchability to 28%, but caused no abnormalities, led Walker to investigate the biological effects and the distribution of malathion injected alone and in various combinations of vegetable oil. He injected 10 eggs with 0.004 ml (5 mg) of undiluted malathion preincubated 3 days; seven embryos survived 20 days and there were no deformities. These results were compared with 0.05 ml of malathion and 0.05 ml of corn oil injected separately into 24 eggs. Eighty-three percent survived 20 days, and 38% (based on the number of eggs injected) of the embryos were deformed. The deformities included abnormal down, hooked beaks, and shortened legs and toes.

Walker (1968) felt that uncontrolled initial movement of the injected material in the yolk could expose the embryo to an overwhelming amount of chemical immediately or to an unknown concentration after an indefinite delay. In order to overcome these limitations, Walker tried yolk chemical mixtures to replace normal egg yolk in teratogenicity studies. Among the insecticides chosen for the tests was malathion. His yolk displacement mixtures consisted of 20% salt-glucose-antibiotic solution and 80% yolk of an unincubated egg from the source used to provide the embryo. The results of the injection methods and replacement methods are summarized as follows.

Treatment	Total mortality (% of number started)	
	Injection method	Replacement method
Malathion, 30 μmoles/egg	100	38
Malathion, 15 μmoles/egg	97	26
Malathion, 7.5 μmoles/egg	80	7
Malathion, 3.75 μmoles/egg	13	--
Control	10	27

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[1] McLaughlin, J., Jr., J. P. Marliac, M. J. Verrett, M. K. Mutchler, and O. G. Fitzhugh, "The Injection of Chemicals into the Yolk Sac of Fertile Eggs Prior to Incubation as a Toxicity Test," Toxicol. Appl. Pharmacol., 5:760-771 (1963).

[2] "Combinations Raise Insecticide Toxicity," Chem. Eng. News, 44:28 (1966).

Typical deformities observed were shortened tibiofibulae, shortened toes, sparse or clubbed down, and hooked beaks or occasionally an elongated upper beak. Walker felt that embryos treated by yolk replacements survived better when pesticide levels were high, less well when they were low, and better when embryos were given injections in corn oil. Abnormalities caused by single pesticides or combinations of two pesticides at low levels were more numerous and more severe after yolk replacement.

Walker (1971) has studied the effect of malathion and malaoxon on esterases and the gross development of chick embryos. There were very few survivors of the embroys at the 16th day of incubation when eggs were treated with 30 µmoles of malaoxon. However, about half of those given 30 µmoles of malathion, or 15 µmoles of malaoxon, and two-thirds of those given 15 µmoles of malathion survived to 18 to 20 days. Embryos given 30 µmoles of malaoxon were very severely deformed. Some of the deformities were small body, little or no down, severely deformed legs and feet, and hooked beak. Embryos given 30 µmoles of malathion had similar but less severe abnormalities. About half of the group that received 15 µmoles of malathion had deformities. However, practically no deformities occurred in embryos where eggs were exposed to 15 µmoles of malaoxon.

Khera and Lyon (1968) injected a number of pesticides in the yolk sacs of chicken and duck eggs on incubation days varying from 0, 4, and 7 for hen eggs, and 0, 4, 7, and 10 for duck eggs. They felt that there was a large variance among replicates, and a lack of dose-response relationship which would render chicken and duck eggs unsuitable for toxicity tests. However, when these two avian species were injected on mid-incubation age (10 days in chick embryos and 13 days in duck embryos), they were capable of providing useful information for the assessment of toxic pesticides. Percent adjusted survivals for chicks and duck embryos injected in the malathion levels at embryonic age of 10 to 13 days, respectively are shown as follows.

	Adjusted percent survival chick embryos		
Replicate No.	10 µg	100 µg	1 mg
1	74	89	84
2	57	103	80
3	95	95	95
4	86	111	86
	Duck embryos		
1	120	76	--
2	99	--	98

These investigators felt that these data indicated a nonmonotonic response to dose. The survival of embryos exposed to 1 mg of malathion was high.

Upshall et al. (1968) studied the teratogenic action of a number of neuroactive agents in developing hen eggs. They reported that when they injected (day 4) 1 mg of malathion per egg, no teratogenic signs were detectable. The length of embryo parts (average of 8 to 25 embryos) indicated no difference between malathion injected eggs and controls. Furthermore, cholinesterase of the embryo was not decreased.

Roger et al. (1969) also reported that malathion injected into the egg at a level of 1 mg/egg reduced hatchability to 70% as compared to the controls at 95% hatchability. There was no indication of parrot beak, or abnormalities of the legs or feathers.

A histochemical study of the developing tibiotarsus in malathion tested chick embryos has been reported (Ho and Gibson, 1972). Embryos were collected at days 8, 10, 12, 14, 16, 18, and 20 of incubation. The yolk mass in each instance was injected with 0.1 ml of 2% malathion (95% technical) in corn oil on day 5 of incubation. Changes in the ossification reflected changes in the cartilage model. In general the tibiotarsi in birds treated with malathion had a reduced rate of matrix function and a more extensive mineralization pattern.

Mollusca - Davis and Hidu (1969)[1] tested 52 compounds as to their effects on embryos of the hard clam, Mercenaria mercenaria, and the American oyster Crassostrea virginica, and on their larvae. The results of experimentation with malathion in acetone solution are shown as follows.

Malathion concentration (ppm)	Eggs developed (%)	Larval survival (%)	Difference in larval length (%)
0.25	104	90	86
0.50	95	88	90
1.00	101	66	77
2.50	89	52	74
5.00	85	20	72
10.00	42	3	41

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[1] Davis, H. C., and H. Hidu, "Effects of Pesticides on Embryonic Development of Clams and Oysters and on Survival and Growth of the Larvae," Fish. Bull., 67(2):393-403 (1969).

There was a gradual inhibition in the survival of larvae and in the percentage increase in length of the larvae as the concentrations were increased from 0.25 ppm to 10 ppm. At the highest dosage level, the development of eggs had been reduced to 42%, the survival of the larvae was down to 3%, and there was only a 41% increase in larval length. They determined from their data that the TL_m values for 50% of the eggs of oysters to be normal was 9.07 ppm and the TL_m values for 50% of the larvae to survive was 2.66 ppm.

Behavioral Effects

A study of the effect of malathion on the behavior of cats has been reported (Spynu, 1957)[1]. Spynu introduced an oil solution of malathion of 50 mg/kg in the stomach of cats. The cholinesterase activity of the plasma was lowered by 45 to 50%. He determined that there was a latency conditioned reflex in the running time 3 hr after the administration of the chemical. In another test, the animals were given 10 mg/kg malathion daily for 10 days. There was an increased inhibition of cholinesterase activity and a change in the higher nervous activities. These disturbances of the strength of the conditioned reflexes and the activity of cholinesterase were especially evident after an introduction of malathion into the cat at 50 mg/kg, following the previous poisoning.

Kagan, as reported in Medved et al. (1964)[2], experimented with a liquid aerosol of malathion on cats. A concentration of 0.0004 to 0.0008 mg/liter caused a lowering of erythrocyte and serum cholinesterase activities, by 60% and 41%, respectively. He observed a change in the strength of the conditioned reflexes in the cat as expressed by the prolongation of the latency and of running time.

Gershon and Shaw (1961)[3] observed the development of the depressive reactions and schizophrenia, along with severe impairment of memory and difficulty in concentration in 16 subjects exposed for between 1-1/2 and 10 years to organophosphate insecticides. The authors concluded that the incidence of psychiatric disorders may be greater in fruit growing areas than urban areas.

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[1] Spynu, E. I., "The Effect of Some Organophosphorus Insecticides in the Higher Nervous Activities and on the Cholinesterase Activity," The Chemistry and Application of Organophosphorus Compounds, edited by Acad. Sci., USSR, Moscow (1957), quoted by Medved et al. (1964).

[2] Medved, L. I., E. I. Spynu, and Yu. S. Kagan, "The Method of Conditioned Reflexes in Toxicology and Its Application for Determining the Toxicity of Small Quantities of Pesticides," Residue Rev., 6:42-74 (1964).

[3] Gershon, S., and F. H. Shaw, "Psychiatric Sequelea of Chronic Exposure to Organophosphorus Insecticides," Lancet, 1271-1374 (1961).

Toxicity Studies with Tissue Cultures

Gabliks and Friedman (1965)[1/] investigated a number of insecticides as to their toxicity in tissue culture. Two cell lines were used--Chang liver strain and HeLa (a malignant strain). Two test procedures were used for the determination of cytopathogenic effect, inhibition of cell growth, and total cell protein. The TD_{50}, ID_{50}, and ID_{10} values for malathion for cytopathogenicity and growth inhibition of liver cells was 10 µg/ml, 15 µg/ml, and 10 µg/ml, respectively. The response of HeLa cells to an exposure to malathion was TD_{50} - 20 µg/ml; ID_{50} - 13 µg/ml; and ID_{10} - 2 µg/ml. Malathion was cytotoxic in both cell lines and induced progressive morphological changes leading to the destruction of cells. The reaction of the two cell lines to malathion was quite similar. Wilson and Walker (1966)[2/] worked with the cells taken from the pectoral region of 14-day old chick embryos and grown as fibroblasts in monolayers according to standard culture procedures. Two samples of malathion were used, one 95% purity and the other 99+% purity. The results from both samples were essentially the same. It was found that malathion was strongly toxic to the cells above 3.0×10^{-5} M (10 µg/ml). This level caused a net decrease in cell number from the original inoculation, but the decrease was not immediate. The decline in cell numbers came on rapidly after 24 hr.

Gabliks et al. (1967)[3/] evaluated the toxicological effects of a number of insecticides in mouse cell cultures. The TD_{50} value for malathion utilizing mouse liver cells was 1,000 µg/ml as compared to 100 µg/ml in mouse skin cells. The ID_{50} values for malathion was 1,804 µg/ml in mouse liver cells and 106 µg/ml in mouse skin cells.

It is of interest to compare the growth inhibition levels (ID_{50} µg/ml) of mouse liver (NCTC No. 1469) and human liver (Chanh strain) cell cultures determined by Gabliks, et al. (1967). The ID_{50} levels (µg/ml) for mouse liver and human liver cell cultures incubated 24, 48 and 72 hr were 200, 160, 5; and 15, 20, and 50, respectively.

1/ Gabliks, J., and L. Friedman, "Responses of Cell Cultures to Insecticides. I. Acute Toxicity to Human Cells," Proc. Soc. Exp. Biol. Med., 120(1):163-168 (1965).

2/ Wilson, B. W., and N. E. Walker, "Toxicity of Malathion and Mercaptosuccinate to Growth of Chick Embryo Cells *in vitro*," Proc. Soc. Exp. Biol. Med., 121(4):1260-1264 (1966).

3/ Gabliks, J., M. Bantug-Jurilla, and L. Friedman, "Responses of Cell Cultures to Insecticides. IV. Relative Toxicity of Several Organophosphates in Mouse Cell Cultures," Proc. Soc. Exp. Biol. Med., 125(3):1002-1005 (1967).

In mouse liver cells the ID$_{50}$ level of malaoxon is about 11 times less that of malathion at 48 hr, and it is about 360 times that of malathion at 72 hr. In Chang liver cells the toxicity of malaoxon is comparable to that of malathion. These values suggest that marked resistance of mouse liver cells is due to their inability to oxidize malathion to malaoxon, whereas human liver cells appear able to transform malathion to malaoxon. There is another interesting factor of cell culture in that the concentrations of toxic materials at low levels sometimes stimulate cell growth. For instance, in mouse liver cells malathion at 50 μg/ml increased the growth to 160%.

The effects of malathion on mammalian cells relative to comparative cytotoxicity, growth inhibition in acute studies, toxicity in chronic studies, and advanced resistance of cell culture to malathion have been reported by Gabliks and Friedman (1969).[1/] These workers utilized human cells (Chang liver strain and HeLa strain) and cells of mouse origin (mouse liver, NCTC No. 1469, and mouse skin fibroblasts L-929). The purity of the test insecticide, malathion, was 99.6%. The comparative cytopathogenicity and growth inhibition of malathion determined in human Chang liver and HeLa cells was as follows:

Cytopathogenicity	Growth inhibition		Cytopathogenicity	Growth inhibition	
TD$_{50}$	ID$_{50}$	ID$_{10}$	TD$_{50}$	ID$_{50}$	ID$_{10}$
(μg/ml)			(μg/ml)		
10	15	10	20	13	2

Gabliks and Friedman (1969) also developed data on the comparative cytotoxicity of malathion to mouse cell cultures as follows:

Growth inhibitory levels (ID$_{50}$ - μg/ml/culture)			ID$_{50}$ mg/kg mouse (per OS)
Mouse liver 1469	Mouse skin L-929	Human liver Chang	
1,804	106	15	720-3,300

[1/] Gabliks, J., and L. Friedman, "Effect of Insecticides on Mammalian Cells and Virus Injections," Ann. N.Y. Acad. Sci., 160(Art. 1): 254-271 (1969).

When the data are compared to the preceding data on the comparative cytotoxicity of malathion to mouse cell culture, it is obvious that malathion is far less toxic to mouse cell cultures. The investigators felt that the difference in susceptibility may have been due to the rates of inactivation to nontoxic derivatives in tissue culture and conversion to more toxic substances *in vivo*.

The results were interpreted by the investigator to mean that the resistance of mouse liver cells to the insecticide could be partially explained by the inability of mouse liver cells to oxidize malathion to malaoxon. Evidently the Chang liver cells (human origin) transform malathion to malaoxon.

Mutagenic Effects

A review of the literature did not reveal any information on the mutagenic effects of malathion.

Oncogenic Effects

No information was found in the literature concerning the oncogenic effects of malathion.

Effects on Humans

This section is concerned with the effects of malathion on humans. Information is presented on acute and subacute toxicity. The symptoms of malathion poisoning, dermal and inhalation toxicity and the occupational exposure hazards relative to field operations are discussed.

Acute Toxicity - Hayes (1967)[1/] quotes a report by Walters (1957)[2/] that the largest nonfatal dose of malathion has been 200 mg/kg of body weight. Walters (1957) indicated that this case involved a 35-year old female who accidentally ingested 470 ml of a 3% solution of malathion to alleviate a toothache. Hayes (1967) referred to a report by Paul (1960)[3/] indicating that the smallest fatal dose has been 71 mg/kg of body weight. In this instance a 75-year old man ingested 30 to 60 ml of a 5% solution of malathion.

[1/] Hayes, W. J., Jr., "Toxicity of Pesticides to Man--Risks from Present Levels," Proc. R. Soc. Long., 167(1007):101-127 (1967).

[2/] Walters, M. N. I., "Malathion Intoxication," Med. J. Aust., 1:876-877 (1957).

[3/] Paul, A. H., "Poisoning by Organo-Phosphorus Insecticide (Malathion)--Report of a Case," N.Z. Med. J., 59(335):346-347 (1960).

Goldin et al. (1964)[1] reported on a case of intended self-destruction which resulted in a dose of 60 g or 1 g/kg of body weight of malathion. Within 30 min the woman was admitted to the casualty department; the subject was in a coma. Within 24 hr after treatment the patient's state of consciousness had improved and she was able to move her arms and legs sluggishly. The serum cholinesterase activity was less than 22% of normal for the first 9 days. In these severe cases the use of a respirator is very important.

There is a case history of a woman who had intentionally swallowed between 35 and 50 g of malathion (Goulding, 1968[2]). This dosage level had a clearly profound effect and she would not have survived if it had not been for the active and specific treatment that she received in the hospital. Eleven days elapsed before it was possible to wean the patient from atropine. Namba et al. (1970)[3] have referred to reports of deaths occurring in adults that consumed 5 g (Paul, 1960), 25 g, 35 g, and 70 g (Faraga, 1967[4]) of malathion, and severe poisoning following the ingestion of 15 g (Parker and Chattin, 1955; Gitelson et al., 1966[5,6]), and 25 g in adults (Richards, 1964; Crowley, 1966; Glaser and Levin, 1968[7-9]), and 4 g in a 2-year old boy (Tuthill, 1958[10]).

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[1] Goldin, A. R., A. H. Rubenstein, B. A. Bradlow, and G. A. Elliott, "Malathion Poisoning with Special Reference to the Effect of Cholinesterase Inhibition on Erythrocyte Survival," N. Engl. J. Med., 271(25):1289-1291 (1964).

[2] Goulding, R., "Toxicological Case Records," Practitioner, 200:599-600 (1968).

[3] Namba, T. M. Greenfield, and D. Grob, "Malathion Poisoning: A Fatal Case with Cardiac Manifestations," Arch. Environ. Health, 21(4): 533-541 (1970).

[4] Faraga, A., "Fatal, Suicidal Malathion Poisoning," Arch. Toxicol., 23:11-16 (1967).

[5] Parker, G., Jr., and W. R. Chattin, "A Case of Malathion Intoxication in a 10-Year Old Girl," J. Indiana State Med. Assoc., 48:491-492 (1955).

[6] Gitelson, S., L. Aladpemopf, S. Ben-Hadar, and R. Katesalson, "Poisoning by a Malathion-Xylene Mixture," JAMA, 197:819-821 (1966).

[7] Richards, A. G., "Malathion Poisoning Successfully Treated with Large Doses of Atropine," Can. Med. Assoc. J., 91:82-83 (1964).

[8] Crowley, W. J., Jr., and T. R. Johns, "Accidental Malathion Poisoning," Arch. Neurol., 14:611-616 (1966).

[9] Glaser, J., and S. Levin, "Malathion Poisoning Due to Hair Shampoo," Harefuah, 74:261 (1968).

[10] Tuthill, J. W. G., "Toxic Hazards: Malathion Poisoning," N. Engl. J. Med., 258:1018-1019 (1958).

The actual amount absorbed was reduced by inducing vomiting or gastric lavage. Matheson and Hardy (1970)[1] have reported severe poisoning following the ingestion of 30 g of malathion.

There has been a report of an attempted suicide case where 30 g of undissolved malathion was ingested by the subject which was equivalent to 280 mg of malathion per kilogram of body weight, and the patient lived (Desnica, 1965[2]).

Rider et al. (1959)[3] fed one group of five volunteers 16 mg of malathion daily for 88 days. During the last 41 days they also received 3 mg of EPN. No significant depression of RBC or plasma cholinesterase was found in the subjects. Another group was fed 6 mg EPN daily for 88 days. They received 8 mg of malathion the last 44 days of the test. Both of the groups (10 subjects) were fed 42 days more on 6 mg EPN and 16 mg of malathion daily. The plasma and RBC cholinesterase was depressed by 6 mg of EPN and 16 mg malathion. However, no toxic signs were detected.

In another study Moeller and Rider (1962)[4] found that 16 mg of malathion may be ingested daily for as long as 47 days without any significant affect on plasma or red blood cell cholinesterase activity. The ingestion of 24 mg daily for 56 days caused a 25% decrease in blood cholinesterase. The threshold of incipient toxicity appeared to be 24 mg for malathion. The threshold of incipient toxicity is defined as the maximum amount of the drug being tested that can be ingested daily for a prolonged period of time without depressing the pretest level of plasma or red blood cell cholinesterase activity more than 10%.

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[1] Matheson, I., and E. A. Hardy, "Treatment of Malathion Poisoning," Anaesthesia, 25:265-271 (1970).

[2] Desnica, G., "A Case of Severe Peroral Poisoning with Malathion," Luec. Vjesn., 87(4):419-424 (1965).

[3] Rider, J. A., H. C. Moeller, J. Swader, and R. G. Devereaux, "A Study of the Anticholinesterase Properties of EPN and Malathion in Human Volunteers," Clin. Res., 7:81 (1959).

[4] Moeller, H. C., and J. A. Rider, "Plasma and Red Blood Cell Cholinesterase Activity as Indications of the Threshold of Incipient Toxicity of Ethyl-*p*-nitrophenyl Thionobenzenephosphonate (EPN) and Malathion in Human Beings," Toxicol. Appl. Pharmacol., 4:123-130 (1962).

Hayes (1971)[1] quoted work by Mattson and Sedlak (1960)[2] in which one subject was given a dosage of 58 mg in 1 day and the concentration in the urine of malathion reached 27 ppm.

Symptoms of Malathion Poisoning - Namba et al. (1971)[3] have produced one of the outstanding reviews on symptoms of poisoning due to organophosphate insecticides. These authors listed the acute poisoning due to organophosphate insecticides to include the following sequence of events: absorption of organophosphates from the skin, gastrointestinal tract, conjunctivas, or respiratory tract; conversion of some organophosphates in the liver to a more toxic form, that is, malathion to malaoxon; transport to the synapses, inhibition of acetylcholinesterase; accumulation of acetylcholine at the synapses, and initial stimulation and later inhibition of synapses transmission. The symptoms of organophosphate poisoning are attributable to the accumulation of acetylcholine, which produces parasympathetic, sympathetic, motor, and central nervous system manifestations. The onset of the symptoms may have a time interval of 5 min after massive ingestion but is usually less than 12 hr and is always less than 24 hr. The usual cause of death is respiratory failure, which results from weakness of respiratory muscles and depression of the respiratory center. Miosis is one of the most characteristic signs and is found in almost all patients with moderately severe and severe poisoning.

The physiological symptoms characteristic of malathion poisoning have been described by Namba et al. (1970) and Goulding (1968). The initial symptoms include such nonspecific features as malise, anorexia, headache, weakness, anxiety, nausea, and vomiting. Progressive diagnostic symptoms include salivation, sweating, abdominal pains, wheezing respiration, bradycardia, and visual difficulties. At this point muscular fasciculation and tremors may occur. As the condition advances, pinpoint and nonreactive pupils, diarrhea, involuntary defecation and tenesmus, pronounced bronchoconstriction and pulmonary edema, cyanosis, convulsions, prostration, and coma may occur.

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[1] Hayes, W. J., Jr., "Studies on Exposure During the Use of Anticholinesterase Pesticides," Bulletin of the World Health Organization, 44:277-288 (1971).

[2] Mattson, A. M., and V. A. Sedlak, "Ether-Extractable Urinary Phosphates in Man and Rats Derived from Malathion and Similar Compounds," J. Agr. Food Chem., 8:107-110 (1960).

[3] Namba, T., C. T. Nolte, G. Jackrel, and D. Grob, "Poisoning Due to Organophosphate Insecticides: Acute and Chronic Manifestations," Am. J. Med., 50:475-492 (1971).

Ramu et al. (1973)[1] observed marked hyperglycemia and glycosuria without acetonuria in four children who had been exposed to a hair rinse containing 50% malathion in xylene.

Central nervous system effects of organophosphate poisoning include electroencephalographic changes which may persist for several weeks after acute poisoning (Grob et al., 1947[2]).

For diagnosis Namba et al. (1971) felt that the estimate of the erythrocyte cholinesterase was preferred since it reflects the degree of inhibition of synaptic cholinesterase. In acute cases, the serum cholinesterase is inhibited more than 50%. The severity of symptoms parallels the serum cholinesterase activity. A reduction to 20 to 50% of normal is considered to be mild poisoning, 10 to 20% of normal value is classified as moderate to severe poisoning, and less than 10% of the normal value is severe poisoning.

Varnai (1971)[3] reported the pathology observed in a fatality that had a blood cholinesterase inhibition of 78%. The fatal dose of malathion produced damage and local hemorrhages in the brain, the heart and lungs, and hepatomegaly. These histopathology studies revealed perivascular edema, lymphocytes in the cortex, cell and cytoplasm degeneration, pycnotic nuclei, stasis, and local karyolysis in gangalia and alveolar emphysema, bronchitis, and hemorrhagic pneumonia. Mucous membranes in the gastrointestinal tract showed extensive necrosis in this case.

Dermal Effects - The effects of controlled dermal exposure are discussed in the following paragraphs. Other information on dermal exposure is discussed in the section on occupational hazards in field operations later on in this subsection.

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[1] Ramu, A., A. E. Slonim, M. London, and F. Eyal, "Hyperglycemia in Acute Malathion Poisoning," Isr. J. Med. Sci., 9(5):631-634 (1973).

[2] Grob, D., A. M. Harvey, O. R. Langworth, and J. L. Lilienthal, Jr., "The Administration of Diisopropyl Fluorophosphate (DFD) to Man. III. Effect on the Central Nervous System with Special Reference to the Electrical Activity of the Brain," Bull. Johns Hopkins Hosp., 81:257 (1947).

[3] Varnai, L., "Pathology of Malathion Poisoning," Orv. Hetil., 112: 1651-1653 (1971).

Hayes et al. (1960)[1] found that there was no decrease in blood cholinesterase following the dermal application of 1, 5, or 10% malathion dust applied five times weekly for 8 to 16 weeks. Milby and Epstein (1964)[2] were interested in the allergic contact sensitivity to malathion. They worked with 87 male volunteers divided into four groups. A known concentration of 95% pure malathion in ethanol was applied to the skin of each individual. The applications were made with dressings that were left in place 2 days. There was some pretreatment in that the subjects in Group 1 had an area of the skin irritated with a 3-sec freeze with Freon 12 (dichlorodifluoromethane) and were then exposed to 10% malathion. Group 2 subjects were exposed to the same level of malathion but a nonirritated skin site was used. Groups 3 and 4 were irritated with Freon 12 and then exposed to 1.0 and 0.1% of malathion, respectively. After 30 days all the subjects were retested with a nonirritating concentration of malathion (1%) at a new site and this area was observed on 2, 4, and 6 days and graded: 1+ = erythema and edema to 4+ = Bullae. They found that 10% malathion produced contact sensitization and that the reactions were strong. They also found that sensitized persons could react to a very weak dilution of the malathion. In fact, they would react to a commercial preparation of 0.9% of malathion and water.

Gutentag (1959)[3] conducted a pilot study to determine the safety of applying malathion powder (1.1%) dusted over a person's entire body. Ten volunteers were used for this test and they wore the same set of fatigue uniforms during the period of exposure. Three ounces of powder consisting of 98.9% pyrophyllite and 1.1% malathion was applied to the hair, the axilla, the groin, and the feet in the early morning. During the first week the volunteers were allowed to shower 8 hr after exposure. During the second week there were no showers, and the volunteers were not allowed to change their clothes throughout the 80-hr period. The third week the men were dusted twice and did not shower during this time. There were 8 days of dusting during the entire test. There was no significant change in plasma values of cholinesterase. The RBC cholinesterase values dropped significantly in all volunteers on July 15. The following day, however, these RBC cholinesterase levels returned to normal. The reason for this was thought to be contamination

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1/ Hayes, W. J., Jr., A. M. Mattson, J. G. Short, and R. F. Witter, "Safety of Malathion Dusting Powder for Louse Control., Bulletin of the World Health Organization, 22:503-514 (1960).

2/ Milby, T. H., and W. L. Epstein, "Allergic Contact Sensitivity to Malathion," Arch. Environ. Health, 9:434-437 (1964).

3/ Gutentag, P. J., "Cutaneous Application of 1.1% Malathion Powder to Volunteers," Report to the U.S. Army, CWLR 2290 (1959).

of the refrigerated blood with parathion in a laboratory refrigerator. After that episode the bloods were not refrigerated. The volunteers had no complaints from the treatment.

Hayes et al. (1960) investigated the safety of using malathion as a louse control. The need for this work grew out of the recognition that DDT and Gamma-BHC had lost their effectiveness for control of some strains of body lice. Three groups of 10 men each entered the study in 1959 and four groups of 4 to 10 men entered the study or continued in it in May of the same year. The malathion (95%) was incorporated in talc in concentrations of 0.1 and 5% for the original three groups, and at 0.1, 5, and 10% during the summer for the latter groups. The men dusted themselves without their clothing each morning 5 days per week. They each were assigned 90 g of the appropriate formulation, and all of the remaining powder that was not used on the skin was sifted into the clothing. There were only three cases of rash reported throughout the experiment, all of which occurred in the men that received 5 or 10% malathion. Cholinesterase values were obtained, and the concentrations of 1 and 5% malathion produced no significant change in RBC cholinesterase while 10% malathion produced a depletion which approached but was not statistically significant. They found that the upper limit of true average absorption of malathion applied to the skin as a powder is probably slightly less than 10%, and the lower limit is about 4%. They concluded that malathion was safe for control of human head or body lice, especially since infrequent applications in small amounts of 1% powder are effective.

Maibach et al. (1971)[1/] made observations on the regional variation of percutaneous penetration in man. They utilized ^{14}C-labeled insecticides. This material was applied with a microtype pipette to a marked site. The dosage was kept at 4 ug/cm^2. The penetration into the palm and the ball of the foot was similar to the forearm, whereas more penetration of malathion was observed from the abdomen and the dorsal skin of the hand. There was a threefold increase on the forehead and a fourfold increase on the axilla relative to the forearm.

[1/] Maibach, H. I., R. J. Feldmann, T. H. Milby, and W. F. Serat, "Regional Variation in Percutaneous Penetration in Man," Arch. Environ. Health, 23:208-211 (1971).

Inhalation Effects - Golz (1959)[1] exposed 16 male prisoners to sprays from aerosol bombs of 5 and 20% malathion. Four groups of men were exposed at one time. In one test the exposure was 3 g of 5% malathion per 1,000 ft^3, which was an actual exposure of 0.15 g of malathion per 1,000 ft^3. In another test the exposure was to 0.6 g, and in a fourth group the exposure was to 2.4 g of actual malathion per 1,000 ft^3. At no time did these subjects experience any cholinergic symptoms. The RBC cholinesterase activities never fell below 90% of normal. There were some erratic results indicated in the plasma cholinesterase activity in that two subjects suffered depressions to 55 and 37% of normal, respectively. These exposures were considered to be more severe than might reasonably be expected to occur in unsupervised domestic use of malathion. Upon careful observation of the test subjects, it was found that none revealed any significant effects from 84 such exposures in 42 consecutive days.

Other information on inhalation effects is discussed in the following subsection on occupational hazards.

Occupational Exposure Hazards - Occupational hazards involving pesticides may be related to exposure of workers in field operations and manufacturing operations. This subsection is devoted to field operation exposures only. No information was available in the literature concerning the hazards in a malathion manufacturing plant.

The Threshold Limit Value (TLV) for malathion has been set at 10 mg/m^3 (Anon., Am. Conf. of Govt. Ind. Hygienists, 1971[2]).

Spraying operations - Caplan et al. (1956)[3] were interested in the hazards of aerial spraying in populated areas with malathion. The spray material contained about 7.5% malathion. Atmospheric samples were obtained during the period of spray application. It was found that the variation was from 0.067 mg/m^3 in unprotected areas to 0.088 mg/m^3 in partially protected areas. Estimates were also made of the amount of malathion that fell on the various subjects, samples being taken from the head, shoulders, forearm, hands and legs; values ranged from

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[1] Golz, H. H., "Controlled Human Exposures to Malathion Aerosols," AMA Arch. Ind. Health, 19:516-523 (1959).

[2] Anon., American Conference of Government Industrial Hygienists, "Documentation of the Threshold Limit Values for Substances in Workroom Air," 3rd edition (1971).

[3] Caplan, P. E., D. Culver, and W. C. Thielen, "Human Exposures in Populated Areas During Airplane Application of Malathion," AMA Arch. Ind. Health, 14:326-332 (1956).

0.45 μg/cm^2 to 2.82 μg/cm^2 for a man outdoors and from 0.25 μg/cm^2 to 0.56 μg/cm^2 for a man indoors. They summarized by saying that a human subject working in the fields exposed to 0.46 lb/acre of malathion by airplane spraying receives an inspiratory exposure about five times greater than a subject working inside. The outdoor skin exposure is about four times the indoor skin exposure. Furthermore a subject in this test on the ground being subjected to these spray conditions (on a milligram per kilogram basis by skin and respiratory exposures) received an amount that had to be multiplied by factors of 500,000 and 120,000, respectively, to approach the LD_{50} of experimental animals. These investigators made a calculation on measurements relating to the man with highest exposure and projected those measurements to a 40-hr week. They estimated that a man would acquire gradually, over a period of 1 month, less than 45 mg/kg deposited on his skin and less than 11 mg/kg inspired through his nostrils. Compared with LD_{50} values for animals, these above values represent 100 to 200 times less than the acute values. Furthermore, it was the opinion of the investigators that malathion could be used safely for mosquitoes in populated areas.

Culver et al. (1956)[1/] studied the dermal and respiratory exposure of workers applying malathion for the control of mosquitoes. In order to measure the amount deposited on the exposed skin, the workers wore absorbent alpha-cellulose headbands and a similar band wrapped around their ankles under the trouser leg but over the socks. Atmospheric samples were collected by all-glass impingers at the breathing zone of the members of the team. During this test 480 samples, including bands and respirator tabs and gloves, were analyzed for malathion. In addition, a total of 145 impinger samples were analyzed for the insecticide. During the spraying operations the highest average atmospheric concentration ranged between 3 and 9 mg/m^3. These levels were encountered in the path of the spray at 10, 17, and 25 yards. Most of the skin and inspiratory exposure curves showed a drop between 10 and 17 yards. However, in all of the curves there was only a slight drop between 17 and 25 yards. The total exposure time for malathion ranged from 5.23 hr for a jeep driver to 3.91 hr for one of the field observers. The jeep driver received the highest skin exposure, which ranged from 32 to 86 mg. His hand exposure was in the range of 27 to 80 mg. Thus, 85 to 95% of his total skin exposure to malathion was that of his supposedly protected hands (in gloves). Furthermore, the total inspiratory exposures to

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[1/] Culver, D., P. Caplan, and G. S. Batchelor, "Studies of Human Exposure During Aerosol Application of Malathion and Chlorthion," AMA Arch. Ind. Health, 13(6):37-50 (1956).

malathion from the impingement samples were highest for the jeep driver, and ran from 11 to 21 mg. For the men in the field the total inspiratory exposures fell in the range of 1 to 5 mg. Throughout the period of application there were no significant changes attributable to parasympathetic overstimulation in any of the field personnel.

Jegier (1964)[1] assessed the occupational hazards that might exist from respiratory or dermal exposure of spray operators to malathion. At the time of the investigation insecticides were being used in apple orchards and the spraying of field crops which included grain, potatoes, peas, cabbage, carrots, onions, and strawberries. During this spray season he measured the respiratory and dermal exposure to 52 subjects. The air concentration of malathion ranged from 0.41 to 0.76 mg/m^3. The actual exposure to malathion ranged from 0.03 to 0.13 mg/man/hr by the respiratory route and 1.5 to 4.9 mg/man/hr by the dermal route. The formulation from which the evaluations were derived was malathion (25% wettable powder) in concentration of 1 to 2.5 lb/100 gal. It was determined during air-blast spraying at apple orchards and field spraying that the exposure to malathion was less than 0.01% of the toxic dose.

Wolfe et al. (1967)[2] made a study of the potential dermal and respiratory hazard of workers exposed to selected pesticides. The information that was obtained involving malathion is given in Table 18. The dermal exposure from operating a power air-blast sprayer was 30 mg/hr. This value is higher than reported by Jegier (1964), 2.5 mg/hr. The values reported here for respiratory intake were comparable to those reported by Jegier (1964), 0.11 mg/hr versus 0.08 mg/hr. The data indicate that the highest percent toxic dose per hour was 0.02% which was received by operators using high-pressure power handguns and spraying of fruit orchards.

Durham et al. (1965)[3] investigated the effect of organophosphate insecticides on mental alertness. These tests involved general exposure to organophosphate pesticides and were carried out over three spraying seasons--1960, 1961, and 1962. It was not delineated in the

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[1] Jegier, Z., "Health Hazards in Insecticides Spraying of Crops," Arch. Environ. Health, 8:670-674 (1964).

[2] Wolfe, H. R., W. F. Durham, and J. F. Armstrong, "Exposure of Workers to Pesticides," Arch. Environ. Health, 14:622-633 (1967).

[3] Durham, W. F., H. R. Wolfe, and G. E. Quinby, "Organophosphorus Insecticides and Mental Alertness," Arch. Environ. Health, 10:55-56 (1965).

TABLE 18. SPRAYING CONDITIONS RELATED TO DERMAL AND RESPIRATORY EXPOSURE OF WORKERS TO MALATHION[a]

Formulation	AI acre (lb)	Activity	Number of samples analyzed		Value	Dermal (mg/hr)	Respiratory (mg/hr)	Total % toxic dose/hr
			Dermal	Respiration				
0.04-0.08% spray	3.4	Operating power air blast, fruit orchard	44	7	Range	5.9-59	0.02-0.24	0.002-0.02
					Mean	30	0.11	0.01
0.03-0.08% spray	3.4	High pressure power hand gun, fruit orchard	94	13	Range	8.4-194	0.01-0.25	0.003-0.06
					Mean	67	0.09	0.02
4% dust	1.4	Operating power duster	14	4	Range	17-32	0.22-1.23	--
					Mean	23	0.73	0.01
4% dust	1.4	Picking beans 1 day after application	194	6	Range	< 0.5-28	--	< 0.001-0.01
					Mean	3.9	< 0.02	0.001
4% dust	1.4	Picking beans 2 days after application	42	1	Range	< 1.5-4.3	--	--
					Mean	2.1	< 0.02	< 0.001
2.5-5% aerosol	--	Operation of aerosol machine	166	14	Range	3.7-53	0.02-0.10	0.001-0.02
					Mean	29	0.09	0.01
2.5-5% aerosol	--	Observers checking for mosquito control	238	30	Range	2.3-6.4	0.04-0.09	0.001-0.003
					Mean	4.1	0.06	0.002

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[a] Data from Wolfe et al., *op. cit.* (1967).

paper, however, as to the days of exposure to any one of the insecticides. The tests were carried out using the Gersoni U test, which is a self-paced vigilance test of the cross-out type. The other procedure used was an EX test, which was another self-paced vigilance test using a question sheet and an IBM answer sheet for true-false answers. A total of 189 cases of suspected organophosphate poisoning were studied over a 4-year period. These investigators summarized their work by commenting that there was little or no difference in mental alertness among the various exposure groups on five of the six parameters measured. However, with respect to lines completed on the Gersoni U test, the exposure group (1960 test) did not score as well during the exposure period compared to the nonexposure period; this was the only difference indicated. Actually, the control group made a better score during the exposure period than during the nonexposure period. There is no indication that exposure to organophosphate pesticides at levels insufficient to produce clinical illness had any important effect on mental alertness from the results of the complex reaction time test.

Milby and Epstein (1964) had obtained an indication of allergic manifestations of malathion in a control one-exposure study which led them to make an investigation in a field survey. They exposed two groups which were chosen to consist of (1) 157 workers from a mosquito abatement district and (2) 43 poultry ranchers who had used malathion for at least one season in the past 3 years.

A 1% freshly prepared solution of 95% malathion and distilled water was placed on a square of cloth which was applied to the forearms and was allowed to remain in place 2 days. Three days after the removal, the site was observed. It was found that among the 157 mosquito abatement workers 3% showed positive reactions, whereas among the poultry ranchers two of the 43 (4.7%) volunteers had positive reactions.

Watanabe (1972)[1/] analyzed the blood of subjects suspected of acute and chronic poisoning by malathion as a result of spraying operations. Of the 20 cases suspected of chronic organophosphate pesticide poisoning, 14 were positive in terms of their serum organophosphate pesticide levels. The range for malathion was calculated to be 0.007 to 1.075 ppm. These subjects had sprayed various pesticides for 5 to 20 years, but they had been out of the orchard for at least 6 months before the

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[1/] Watanabe, S., "Detection of Organophosphate Pesticides in Blood Serum from Patients Suspected of Acute and Chronic Pesticides Poisonings and Its Clinical Significance," Tohoku J. Exp. Med., 107(3):301-302 (1972).

examination. Blood samples were also taken from 15 cases of acute poisoning and the range of pesticide found in the blood was 0.002 to 0.57 ppm.

Hayes (1971) summarized the observations of a number of workers and concluded that in working areas the observed concentrations for malathion ranged from 0.01 to 0.60 mg/m^3 compared to 0.1×10^{-6} mg/m^3 in surrounding communities. When these values are compared with the threshold limit values of 10 mg/m^3 which were established in 1971 by the American Conference of Government Industrialist Hygienists, it becomes obvious that under most normal spraying or insecticide application conditions the concentrations to which humans are exposed are significantly lower than values considered hazardous.

Accidents - Malathion is one of the pesticides frequently involved in accidental exposure to pesticides. Preliminary data from the EPA Pesticide Accident Surveillance System (PASS) show that malathion is one of the ninth most frequently cited pesticides for all episodes* reported in 1973. The computerized PASS data base, which generally includes any data for 1972 through about January 1974, lists a total of 123 episodes involving accidental exposure to malathion. Data, in addition to the preliminary information found on the pesticide episode reporting form (Form ACC-1, December 1972), however, were available for review on only three of those episodes. These limited data are not sufficient to establish any relationship between the accidents and any specific application or use of malathion.

Summary

Effects on Reproduction - The daily intake of 240 mg/kg (4,000 ppm) of malathion in rats reduced the number of newborn at 7 days of age by 50%.

The inclusion of 100 mg/lb (first 4 weeks), 200 mg/lb (5th through 7th week), and up to 500 mg/lb (8th through 29th week) of malathion did not appear to affect egg production. When eggs were injected with 25, 100, 200, 300, 400, and 500 ppm, hatchability was reduced to 85, 87, 62, 71, 42, and 6%, respectively. When eggs were injected with malathion in combination with Ethion, Mecarbum, Trichlorphion and Morphothion, an enhanced depressant hatchability effect was noted.

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* Episodes reported include those involving humans, animals, plants, and area contamination.

When urban areas were sprayed with 3 ounces of malathion per acre, the house sparrow population was not depleted, and mating and nesting characteristics were not changed.

The sperm of swine in the presence of malathion does exhibit reduced mortality but there is no effect on respiration or glycolysis.

Teratogenic Effects - It has been reported that the injection of 900 mg/kg of body weight of malathion into pregnant rats on the 11th day after insemination did not produce malformation in the young.

It has been reported that the injection of 62 mg of malathion into hen eggs reduced the hatchability by 60% and anomalies occurred in the embryos. In general, the injection of a foreign material into the egg yolk and its action on the embryo depends upon a number of parameters; distribution in the yolk, concentration of varied amounts in possible vital loci, overwhelming levels occurring and the type of vehicle used in the injection.

The injection of 1 mg of malathion in hens eggs does not bring about anomalies of the embryo, however, the hatchability may be reduced by 25%. In one study, the injection of 0.1 ml of a 2% malathion solution brought about changes in bone ossification.

Oysters are affected by malathion to the extent that 10 ppm will reduce egg development (42%), survival of larvae (3%) and the difference in length of larval development (41%).

Behavioral Effects - Studies have been done involving the measuring of malathion toxicity by latency conditioned reflex. The physiological effects of small amounts of the chemical can be detected.

Toxicity Studies With Tissue Cultures - Malathion is cytotoxic to both Chang liver cells (nonmalignant) and HeLa cells (malignant) at concentrations above 3×10^{-5} M (10 μg/ml). The TD_{50} values for malathion in contact with mouse liver and skin cells was 1,000 μg/ml and 100 μg/ml, respectively. The ID_{50} values were 1,804 μg/ml and 106 μg/ml in mouse liver and skin cells, respectively. The ID_{50} for malaoxon is about 11 times (less) that of malathion at 48 hr and 360 times (less) malathion at 72 hr.

Mutagenic and Oncogenic Effects - No information was found in the literature concerning the mutagenic or oncogenic effects of malathion.

Effects on Humans - The acute toxic level of malathion reported for humans appears to vary from 71 mg/kg of body weight for a low dose to an amount equal to or exceeding 1,000 mg/kg of body weight for a high dose. Fast therapeutic action averted death in some of the reported high dose levels.

In controlled studies, 16 mg of malathion have been administered for 47 days without affecting plasma or red blood cell cholinesterase. A 25% decrease in blood cholinesterase has been reported for subjects consuming 25 mg of malathion for 56 days.

Symptoms of Malathion Poisoning - The general characteristics of organophosphorus compounds are exhibited by malathion. Malathion is converted to malaoxon which is a more toxic form. The sequence of poisoning events is malaise, anorexia, headache, weakness, anxiety, nausea and vomiting followed by salivation, sweating, vomiting, abdominal pains, wheezing respiration, bradycardia and visual difficultues. At this point, muscular fasciculation and tremors set in. In the highly progressive state, pronounced bronchoconstriction, pulmonary edema, cyanosis, convulsions, prostration and coma occur.

The pathology of malathion poisoning is generally nonspecific. Local hemorrhages may occur in the brain, heart and lungs. Mucous membranes in the gastrointestinal tract may show extensive necrosis.

Dermal Effects - The application of 1, 5 or 10% malathion dust applied to the skin five times weekly for 8 to 16 weeks does not decrease blood cholinesterase.

When volunteers were exposed to 0.1, 1.0, and 10% solution of malathion applied to the skin as dressing and retained in contact with the skin for 2 days, the 10% solution produced sensitization.

An extensive study of the dermal effects of 1.1% malathion dust has been made by the Army. The dust was in contact with the subjects for a period of 3 weeks and during the first week, the contact was 8 hr a day. Throughout the second week, the subjects did not change clothes for 80 hr. The subjects were dusted twice during the third week and did not shower. There was no significant depression of RBC cholinesterase in these volunteers. In another test, there were no significant toxic effects produced by dusting repeatedly with 5 and 10% malathion dusts.

Inhalation Effects - It has been reported that no toxic manifestations have occurred when subjects were exposed 84 times in 42 consecutive days to a concentration of aerosols ranging from 0.15 mg to 2.4 g of actual malathion per 1,000 ft^3.

Occupational Exposure Hazards - There have been a number of studies of the exposure hazard to spray operations in orchards and field crops and people living in communities where malathion was used for mosquito abatement. It appears that malathion does not represent any hazard to humans in these operations. Exposure under spray conditions would have to be multiplied by a factor of 500,000 and 120,000 to approach the LD_{50} of experimental animals for dermal and respiratory exposure as reported by one investigator. In another study, the calculated exposure in spray operations was less than 0.01% of the toxic dose.

The work of a number of investigators has been examined and the conclusion was made that the concentration of malathion in working areas ranges from 0.01 to 0.60 mg/m^3 and in communities 0.1×10^{-6} mg/m^3. When these values are compared with the threshold limit values (TLV) set by the American Conference of Government and Industrial Hygienists of 10 mg/m^3, it is obvious that the exposure hazard of malathion is very low.

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SUBPART II. C. FATE AND SIGNIFICANCE IN THE ENVIRONMENT

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This section contains data on the environmental effects of malathion, including effects on aquatic species, wildlife, and beneficial insects, interactions with lower terrestrial organisms and effects on residues in soil, water and air. The section summarizes rather than interprets data reviewed.

Effect on Aquatic Species

Fish -

Toxicity - The acute toxicity of malathion to various species of fish is shown in Table 19. (Scientific names of fish species are given in Table 20.) As shown, the toxicity of malathion to fish varies as to the species and as to the way toxicity is expressed. This toxicity ranges from a high with bluegill to a low with mummichog. It appears that young bluegill are more susceptible to malathion than older bluegill (Pickering et al., 1962[1/]).

Available data on the subacute and chronic toxicity of malathion to fish are summarized in Table 21.

Signs of malathion poisoning in fish consisted of uncoordinated movements, swimming on sides, air searching, and finally cessation of gill movement (Murphy, 1967[2/]). Death was preceded by an involuntary extension of the pectoral fins. A reddish discoloration due to hemorrhaging in the muscle beneath the dorsal fin was evident. Brain cholinesterase depression to one-third of the control value was found at toxicant concentrations considered to be safe. Malathion also caused high percentages of spinal deformities at 7.4 ppb. (Eaton, 1970[3/]).

Field studies - Kennedy and Walsh (1970)[4/] studied the toxicity of malathion to the bluegill (*Lepomis macrochirus*) and the channel catfish (*Ictalurus punctatus*) in ponds which were treated four times at the rate of 0.002 or 0.02 ppm over an 11-week period. Fish mortality ranged from 8 to 44%, but was not correlated with the treatment levels.

[1/] Pickering, Q. H., C. Henderson, and A. E. Lemke, "The Toxicity of Organic Phosphorus Insecticides to Different Species of Warmwater Fishes," *Trans. Am. Fish Soc.*, 91(2):175-184 (1962).

[2/] Murphy, S. D., "Malathion Inhibition of Esterases as a Determinant of Malathion Toxicity," *J. Pharmacol. Exp. Ther.*, 156:352-365 (1967).

[3/] Eaton, J. G., "Chronic Malathion Toxicity to the Bluegill (*Lepomis macrochirus* Rafinesque)," *Water Res.*, 4:673-684 (1970).

[4/] Kennedy, H. D., and D. F. Walsh, "Effects of Malathion on Two Warmwater Fishes and Aquatic Invertebrates in Ponds," U.S. Bureau of Sport Fisheries and Wildlife Tech. Paper No. 55, 13 pages (1970).

Table 19. ACUTE TOXICITY OF MALATHION TO FISH

Fish tested	Exposure time (hr)	Toxicity calculation	Toxicity measured (ppm)	References
Fathead minnow	96	TL_m	9	a/
Fathead minnow	96	TL_m	23.5	b/
Fathead minnow	24	TL_m	26.0	c/
Fathead minnow	48	TL_m	24.0	c/
Fathead minnow	96	TL_m	23.0	c/
Fathead minnow	24	TL_m	25.0*	c/
Fathead minnow	48	TL_m	25.0*	c/
Fathead minnow	96	TL_m	25.0*	c/
Fathead minnow	96	TL_{50}	8.65	d/
Fathead minnow	96	LC_{50}	12.5	e/, f/
Bluegill	24	TL_m	0.14	c/
Bluegill	48	TL_m	0.12	c/
Bluegill	96	TL_m	0.090	c/
Bluegill - small	24	TL_m	0.60†	c/
Bluegill - small	48	TL_m	0.55†	c/
Bluegill - small	96	TL_m	0.55†	c/
Bluegill - large	24	TL_m	1.7†	c/
Bluegill - large	48	TL_m	1.3†	c/
Bluegill - large	96	TL_m	1.2†	c/
Bluegill	24	TL_m	0.19*	c/
Bluegill	48	TL_m	0.11*	c/
Bluegill	96	TL_m	0.088*	c/
Bluegill	96	TL_{50}	0.103	d/
Bluegill	96	TL_{50}	0.11	g/
Carp	48	TL_m	10.0	h/
Carp	48	LC_{100}	13.5	h/
Rainbow trout	96	TL_{50}	0.170	d/
Rainbow trout	24	17% mortality	1	i/
Rainbow trout	48	17% mortality	1	i/
Rainbow trout	96	26% mortality	1	i/
Rainbow trout	24	100% mortality	10	i/
Brook trout	48	LC_{50}	0.2	f/
Green sunfish	24	TL_m	1.2†	c/
Green sunfish	48	TL_m	0.70†	c/
Green sunfish	96	TL_m	0.60†	c/
Red ear sunfish	96	TL_{50}	0.17	d/
Largemouth bass	24	TL_m	0.42†	c/
Largemouth bass	48	TL_m	0.28†	c/
Largemouth bass	96	TL_m	0.25†	c/
Largemouth bass	96	TL_{50}	0.285	d/
Tilapia	48	TL_m	5	j/
Tilapia	48	TL_m	8.3	h/
Tilapia	48	LC_{100}	10.0	h/
Black bullhead	96	TL_{50}	12.9	d/
Striped bass	24	LC_{50}	0.79	k/
Striped bass	48	LC_{50}	0.46	k/
Striped bass	96	LC_{50}	0.24	k/
Goldfish	96	TL_{50}	10.7	d/
Goldfish	24	TL_m	0.79*	c/
Goldfish	48	TL_m	0.79*	c/
Goldfish	96	TL_m	0.79*	c/
Guppy	24	TL_m	0.93	c/
Guppy	48	TL_m	0.88	c/
Guppy	96	TL_m	0.84	c/

Table 19. (Concluded)

Fish tested	Exposure time (hr)	Toxicity calculation	Toxicity measured (ppm)	References
Channel catfish	96	TL_{50}	8.97	d/
Channel catfish	96	TL_{50}	0.76	g/
Brown trout	96	TL_{50}	0.200	d/
Coho salmon	96	TL_{50}	0.101	d/
Yellow perch	96	TL_{50}	0.263	d/
Mummichog	96	LC_{50}	70	l/
Harlequin fish	24	LC_{50}	10	m/
Cirrhina mrigola	48	TL_m	7	h/
Cirrhina mrigola	48	LC_{100}	15	h/
Labeo fimbreatus	48	TL_m	8.5	h/
Labeo fimbreatus	48	LC_{100}	12.0	h/
Labeo rohita	48	TL_m	8.0	h/
Labeo rohita	48	LC_{100}	10.0	h/
Danio sp.	48	TL_m	13.5	h/
Danio sp.	48	LC_{100}	14.0	h/
Walleye pike	24	0% mortality	0.74	n/
Walleye pike	24	95% mortality	1.84	n/

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* Emulsifiable concentrate 57%.

† Emulsifiable concentrate 20%.

a/ Mount, D. I., and C. E. Stephan, "A Method for Establishing Acceptable Toxicant Limits for Fish--Malathion and the Butoxyethanol Ester of 2,4-D," Trans. Am. Fish. Soc., 96:185-193 (1967).

b/ Bender, M. E., "Toxicity of the Hydrolysis and Breakdown Products of Malathion to the Fathead Minnow (Pimephales promelas)," Water Res., 3(8):571-582 (1969).

c/ Pickering et al., op. cit. (1962).

d/ Macek, K. J., and W. A. McAllister, "Insecticide Susceptibility of Some Common Fish Family Representatives," Trans. Am. Fish. Soc., 99(1):20-27 (1970).

e/ Katz, M., "Acute Toxicity of Some Organic Insecticides to Three Species of Salmonids and to the Threespine Stickleback," Trans. Am. Fish. Soc., 90(3):264-268 (1961).

f/ Pimentel, D., "Ecological Effects of Pesticides on Nontarget Species," Executive Office of the President, Office of Science and Technology, U.S. Government Printing Office, Washington, D.C. (1971).

g/ Kennedy and Walsh, op. cit. (1970).

h/ Sreenivasan, A., and G. K. Swaminathan, "Toxicity of Six Organophosphorus Insecticides to Fish," Curr. Sci., 36:397-398 (1967).

i/ Lewallen, L. L., and W. H. Wilder, "Toxicity of Certain Organophosphorus and Carbamate Insecticides to Rainbow Trout," Mosquito News, 22(4):369-372 (1962).

j/ Sreenivasan, A., and R. R. Saundar, "Toxicity of Malathion and Parathion to Fish," Symposium on Pesticides, Mysore, India, 1961, pp. 316-318 (1968).

k/ Wellborn, T. L., "Toxicity of Some Compounds to Striped Bass Fingerlings," Prog. Fish Cult., 33(1):32-36 (1971).

l/ Eisler, R., Jr., "Factors Affecting Pesticide-Induced Toxicity in an Estuarine Fish," U.S. Bureau of Sport Fisheries and Wildlife Tech. Paper No. 45, pp. 1-20 (1970).

m/ Alabaster, J. S., "Survival of Fish in 164 Herbicides, Insecticides, Fungicides, Wetting Agents and Miscellaneous Substances," Int. Pest. Control, 11(2):29-35 (1969).

n/ Hilsenhoff, W. L., "Toxicity of Granular Malathion to Walleyed Pike Fingerlings," Mosquito News, 22:14-15 (1962).

Table 20. COMMON AND SCIENTIFIC NAMES OF FISH USED IN CONTROLLED TOXICITY TESTS WITH MALATHION

Common name	Scientific name
Fathead minnow	Pimephales promelas
Bluegill	Lepomis macrochirus
Carp	Cyprinus carpio
Rainbow trout	Salmo gairdneri
Brook trout	Salvelinus fontinalis
Green sunfish	Lepomis cyanellus
Pumpkinseed	Lepomis gibbosus
Largemouth bass	Micropterus salmoides
Mummichog	Fundulus heteroclitus
Tilapia	Tilapia aurea
Striped mullet	Mugil cephalus
Golden shiner	Notemigonus crysoleusas
Black bullhead	Ictalurus melas
Mosquito fish	Gambusia affinis
Rice fish	Oryzias latipes
Goldfish	Carassius auratus
Guppy	Lebistes reticulatus
Yellow perch	Perca flavescens
Walleye pike	Stizostedian vitreum vitreum
Channel catfish	Ictalurus punctatus
Brown trout	Salmo trutta
Coho salmon	Oncorhynchus kisutch
Striped bass	Morone saxatilis
Hawkfish	Cirrhina mrigola
Harlequin fish	Rasbor heteromorpha
Red ear sunfish	Lepomis microlophus
Striped bass	Morone saxatilis
Hawkfish	Cirrhina mrigola
Harlequin fish	Rasbor heteromorpha

Table 21. SUBACUTE AND CHRONIC TOXICITY OF MALATHION TO FISH

Fish tested	Exposure time (days)	Toxicity calculation	Toxicity measured (ppm)	References
Bluegill	7	LT_c	0.079	a/
Bluegill	11	LT_c	0.085	a/
Mummichog	10	LC_{50}	70.0	b/
Fathead minnow	4 months	TL_m - 96 hr	9	c/
Fathead minnow	4 months	Maximum acceptable conc.	0.2-0.58	c/

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a/ Eaton, *op. cit.* (1970).
b/ Eisler, *op. cit.* (1970).
c/ Mount and Stephan, *op. cit.* (1967).

There were no differences in fish growth or microhematocrit values between the fishes in the treated and untreated ponds. No acute or chronic pathology developed, and no significant depression of brain cholinesterase was observed. Bluegills spawned twice during the study period.

A number of authors investigated the toxicity of malathion to estuarine fish, with a view to its use for the control of mosquito larvae in salt marshes. Darsie and Corriden (1959)[1] performed a series of field tests to ascertain the toxicity of malathion to killifish (family Cyprinodontidae) in tidal marshes in Delaware. Groups of 25 fish each were exposed in metal tubs containing 7 gal. of habitat water. Malathion was applied at the rate of 0.5 lb AI/acre aerially to simulate practical mosquito control procedures. Among fish exposed for 4 hr, 26% died, 42% were sublethally poisoned, and 31% were unaffected. The fate of the moribund fish was followed for 64 hr after treatment. Of these, 66% recovered, 8% still showed symptoms at the end of the observation period, and 26% died.

Westman and Compton (1960)[2] reported that the exposure of salt marsh killifishes (Cyprinodon variegatus) to malathion at a concentration of 0.1 ppm resulted in 30% mortality, and approximately 80% crippled fishes. Lower temperatures delayed mortality and crippling; the higher the temperature, the quicker the effect. The authors point out that in nature, crippled fish usually are victims of early predation.

Joseph et al. (1972)[3] studied the effects of ultra-low-volume (ULV) field applications of malathion to goldfish. Malathion was applied at the recommended rate, 1.5 fl oz/min, and at 10 times that rate. After 20 separate applications within a 34-day period, the exposed fish did not exhibit any detectable neurotoxic symptoms.

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[1] Darsie, R. F., Jr., and F. E. Corriden, "The Toxicity of Malathion to Killifish (Cyprinodontidae) in Delaware," J. Econ. Entomol., 52:696-700 (1959).

[2] Westman, J. R., and K. Compton, "Responses of Salt Marsh Killifishes to Certain Environmental Changes and to Malathion," Proc. New Jersey Mosquito Extermination Assoc., 47:116-123 (1960).

[3] Joseph, S. R., J. Mallack, and L. F. George, "Field Applications of Ultra-Low-Volume Malathion to Three Animal Species," Mosquito News, 32:504 (1972).

Coppage and Duke (1971)[1] monitored the effects of malathion sprayed by aircraft for mosquito control purposes over two Louisiana lakes. Three species of fish (spot, Leiostomus xanthurus; Atlantic croaker, Micropogon undulatus; and striped mullet, Mugil cephalus) were collected and assayed for brain acetylcholinesterase (AChE) activity. Fish from the lake that was treated at the rate of 3 oz of malathion AI per acre exhibited significant AChE inhibition, ranging from about 20 to 80%. Fish kills were reported during the spraying period, and moribund fish were collected. Malathion at the same rate was also applied around a second lake, but in this case not over open waters. Only a few fish collected from this lake were found to have significant AChE inhibition.

Tagatz et al. (1974)[2] investigated the effects on sheepshead minnows (Cyprinodon variegatus) of malathion sprayed on a salt marsh near Pensacola Beach, Florida. Malathion was applied as a thermal fog at 6 oz AI/acre and as a ULV aerosol spray at 0.64 fl oz/acre three times in succession, typical of usual mosquito control operations. There was no fish mortality, and no brain AChE depression was observed in confined fish exposed to one or more treatments.

In 1966, malathion was used for the control of grasshoppers on Indian reservations in Montana and Wyoming, and in the Dixie National Forest, Utah. Morton (1966)[3] reported that no dead fish were observed in a stream or in live-boxes following the aerial application of malathion (dosage rate not specified) on the Crow Indian Reservation,

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[1] Coppage, D. L., and T. W. Duke, "Effects of Pesticides in Estuaries Along the Gulf and Southeast Atlantic Coasts," Proc. of the 2nd Gulf Coast Conference on Mosquito Suppression and Wildlife Management, pp. 26-30 (1971).

[2] Tagatz, M. E., P. W. Borthwick, G. H. Cook, and D. L. Coppage, "Studies on Effects of Ground Applications of Malathion on Salt-Marsh Environments in Northwestern Florida," unpublished manuscript, submitted to Mosquito News, 16 pages (1974).

[3] Morton, W. M., "Malathion Grasshopper Control Project on the Crow Indian Reservation in Yellowstone and Big Horn Counties, Montana," U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Pesticide Surveillance Program, Special Report, 10 pages, 8 figures, 4 tables (1966).

Montana. Henderson (1967a)[1] reported "minimal effects on fish" following aerial application of technical malathion at the rate of 7.9 fl oz/acre to 37,440 acres on the Wind River Indian Reservation, Wyoming. Henderson (1967b)[2] also monitored the effects of the application of malathion at the rate of about 8 fl oz/acre to 4,300 acres in the Dixie National Forest, Utah. In this case, about 80 dead brook trout ranging in size from 3 to 14 in. were found. Most of the fish mortality occurred in areas where overlapping of spray swaths was observed. Brain AChE levels in samples of these dead fish were near zero. All fish confined in live-boxes in the same area survived the treatment. Henderson suggests that wild unconfined fish obtained additional exposure to the insecticide by feeding on dead insects.

Kerswill and Edwards (1967)[3] monitored the survival of young Atlantic salmon and eastern brook trout sprayed with malathion for budworm control. The trout, found in New Brunswick, Connecticut streams, were studied in their natural habitat and in caged environments. Malathion at 0.8 lb/acre had no apparent short-term effects on salmon parr, but killed many under a year old.

Giles (1970)[4] studied the effects on the faunal ecology of an aerial application of malathion at 0.7 lb AI/acre to a 19.8-acre watershed covered by deciduous forest in Ohio. Fishes and crayfishes which were sensitive to malathion in laboratory tests were unaffected in the stream environment.

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[1] Henderson, C., "Little Wind Grasshopper Control Project, Wind River Indian Reservation, Wyoming," U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Pesticide Surveillance Program, Special Report, 20 pages, 9 figures (1967a).

[2] Henderson, C., "Podunk Grasshopper Control Project, Dixie National Forest, Utah," U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Pesticide Surveillance Program, Special Report, 24 pages, 9 figures (1967b).

[3] Kerswill, C. J., and H. E. Edwards, "Fish Losses After Forest Spraying with Insecticides in New Brunswick, 1952-1962, as Shown by Caged Specimens and Other Observations," Fish Res. Board Can. J., 24(4):709-729 (1967).

[4] Giles, R. H., Jr., "The Ecology of a Small Forested Watershed Treated with the Insecticide Malathion-^{35}S," Wildlife Monographs, No. 24, 81 pages (1970).

Shea (1970)[1] reported that an estimated 349,000 fish were killed in a creek near Troy, Missouri, as a result of careless dumping of a mixture of chlordane and malathion in xylene on the ground about 100 yd from the creek. However, no data are provided that would allow separation of the relative contribution of malathion in this episode, nor on the concentrations of malathion to which the fish were exposed.

Hansen (1969)[2] and Hansen et al. (1972)[3] studied the capacity of fish to avoid pesticides, including malathion. Sheepshead minnows (*C. variegatus*) did not avoid the test concentrations of malathion, while they were able to avoid several other pesticides tested in the same manner. Mosquitofish (*Gambusia affinis*) showed a real, but not pronounced, ability to avoid water contaminated with malathion (and several other insecticides).

Wilson (1966)[4] investigated the toxicity of malathion and several of its metabolites to the fathead minnow (*Pimephales promelas*). The following 96-hr LC_{50} values (ppm) were obtained: malathion, 14; diethyl succinate, 18; malic acid, 25; mercapto succinic acid, 30; diethyl fumarate, 38; diethyl maleate, 41; dimethyl phosphite, 225; dimethyl phosphate, 250. By contrast, Bender (1969) reported that the "basic hydrolysis product" of malathion, diethyl fumarate, was more toxic than malathion itself to fathead minnows. Interestingly, this author found a pronounced synergistic effect between malathion and its two basic hydrolyses products. Continuous exposure (14 days) decreased the mean lethal time concentration of malathion as well as of its hydrolysis products.

Only one report was found on the toxicity of malathion to fishes. Liska (1971)[5] reported the toxicity threshold for (unspecified) fishes for malathion at 0.2 mg/liter.

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[1] Shea, K. P., "Dead Stream," *Environment*, 12(6):12-15 (1970).

[2] Hansen, D. J., "Avoidance of Pesticides by Untrained Sheepshead Minnows," *Trans. Am. Fish. Soc.*, 98(3):426-429 (1969).

[3] Hansen, D. J., E. Matthews, S. L. Nall, and D. P. Dumas, "Avoidance of Pesticides by Untrained Mosquitofish, *Gambusia affinis*," *Bull. Environ. Contam. Toxicol.*, 8(1):46-51 (1972).

[4] Wilson, B. R., "Fate of Pesticides in the Environment - A Progress Report," *Trans. New York*, N. Y. Acad. Sci., 28:694-705 (1966). Quoted from Pimentel (1971).

[5] Liska, D., "Sanitary-Hygienic and Toxicological Problems of Pesticide Residues in Some Spheres of the Environment," *Lek. Obz.*, 29(1): 11-15 (1971).

The data reviewed indicates that malathion is highly toxic to fish, and that the potential for damage to fish populations exists when malathion is used at insecticidally effective rates of application. In view of the large-scale use of malathion (including uses over or near aquatic environments) and the somewhat contradictory reports on the fish toxicity of malathion degradation products, there appears to be a need for more information on the toxicity of malathion degradation products to fish (as well as to other nontarget organisms), and on the persistence and fate of these degradation products in the aquatic (and terrestrial) environment.

Other Aquatic Biota - For purposes of this review, "other aquatic biota" are defined to include primary producers (phytoplankton, attached algae, moss, and vascular plants); consumers (protozoa, rotifers, and crustacea); benthic invertebrates (annelids, insects, crustacea, and mollusca); and decomposers (fungi and bacteria).

Laboratory studies - In static bioassay tests on the toxicity of malathion to aquatic organisms, the following 48-hr TL_m values were found: Stonefly, *Pteronarcys badia* (6); water flea, *Daphnia pulex* (1.8); brook trout, *Salvelinus fontinalis* (19.5); and for amphipod, *Gammarus lacustris* (1.8).[1/]

Data on the toxicity of malathion to three species of *Daphnia* and to *Simocephalus serrulatus* is presented in Table 22. The EC_{50} (immobilization) values of malathion to the zooplankton species ranged from 0.2 to 6.2 ppb, depending upon test species, temperature, and exposure time.

Data on the toxicity of malathion to benthic invertebrates is presented in Table 23. The LC_{50} values of malathion to several species of stoneflies, caddisflies, and mayflies and to one amphipod species, vary over an even wider range, again depending upon the test species and the experimental conditions.

[1/] Federal Water Pollution Control Administration, *Water Quality Criteria: Report of the National Technical Advisory Committee*, p. 37 (1968)

Table 22. EC_{50} (IMMOBILIZATION) VALUES (ppb) OF MALATHION TO ZOOPLANKTON

Species	Temperature	Time (hr)	EC_{50} ppb	References
Daphnia pulex	21°C	48	2	a/
	60°F	48	1.8	b/
	60°F	48	1.8	c/
Daphnia magna	68°F	24	0.9	b/
	68°F	50	0.9	b/
	20°C	50	0.9	d/
Daphnia carinata	78°F	64	0.2	e/
Simocephalus serrulatus	60°F	48	3.5	b/
	70°F	48	6.2	b/

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a/ Cope, O. B., "Contamination of the Freshwater Ecosystem by Pesticides," J. Appl. Ecol., 3(Suppl):33-44 (1966). In: Li and Fleck (1972).

b/ Sanders, H. O., and O. B. Cope, "Toxicities of Several Pesticides to Two Species of Cladocerans," Trans. Am. Fish. Soc., 95(2):165-169 (1966).

c/ Federal Water Pollution Control Administration, "Water Quality Criteria," Report of the National Technical Advisory Committee, p. 37 (1968).

d/ Anderson, B. G., "The Toxicity of Organic Insecticides to *Daphnia*," in: Transactions of the Second Seminar on Biological Problems in Water Pollution, Cincinnati, Ohio, U.S. Public Health Service, pp. 94-95 (1959). In: Li and Fleck (1972).

e/ Matida, Y., and N. Kawasaki, "Study on the Toxicity of Agricultural Control Chemicals in Relation to Freshwater Fisheries Management," No. 2, Toxicity of Agricultural Insecticides to *Daphnia carinata*, King. Bull. Freshwater Fish. Res. Lab., Tokyo, 8:1-6 (1958). In: Li and Fleck (1972).

Source: Li, M., and R. A. Fleck, "The Effects of Agricultural Pesticides in the Aquatic Environment, Irrigated Croplands, San Joaquin Valley," Pesticide Study Series - 6. Environmental Protection Agency, Office of Water Programs, Applied Technology Division, Rural Waste Branch TS-00-72-05, 268 pages (1972).

Table 23. LC$_{50}$ VALUES (ppb) OF MALATHION TO BENTHIC INVERTEBRATES

Species	Temperature	Time (hr) (* = days)	LC$_{50}$ ppb	References
Stoneflies				
Pteronarcys californica	15.5°C	24	35.0	a/
	15.5°C	48	20.0	a/
	21°C	48	21.0	b/
	11-12°C	48	180.0	d/
	11-12°C	72	72.5	d/
	11-12°C	96	50.0	d/ e/
	15.5°C	96	10.0	a/
	12.8°C	5*		f/
	12.8°C	10*		f/
	12.8°C	15*	45.0	f/
	12.8°C	20*	24.0	f/
	12.8°C	25*	15.5	f/
	12.8°C	30*	8.8	f/
Acroneuria pacifica	11-12°C	48	12.0	d/
	11-12°C	72	16.0	d/
	11-12°C	96	7.0	d/, e/
	12.8°C	5*	7.7	f/
	12.8°C	10*	5.1	f/
	12.8°C	15*	3.3	f/
	12.8°C	20*	3.2	f/
	12.8°C	25*	2.4	f/
	12.8°C	30*	0.78	f/
Pteronarcella badia	15.5°C	24	10.0	a/
	15.5°C	48	60.0	a/
	48-50°F	48	6.0	c/
	15.5°C	96	1.1	a/
Classenia sabulosa	15.5°C	24	13.0	a/
	15.5°C	48	6.0	a/
	15.5°C	96	2.8	a/
Caddisflies				
Arctopsyche grandis	51-54°F	96	32.0	e/
Hydropsyche californica	51-54°F	96	22.5	e/
Mayflies				
Ephemerella grandis	48-50°F	96	100.0	e/

Table 23. (Continued)

Species	Temperature	Time (hr) (* = days)	LC_{50} ppb	References
Baetis sp.	21°C	48	6.0	b/
Amphipods				
Gammarus lacustris	70°F	24	3.8	g/
	70°F	48	1.8	g/
	60°F	48	1.8	c/
	70°F	48	1.0	g/
	59°F	96	1.62	e/

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a/ Sanders, H. O., and O. B. Cope, "The Relative Toxicities of Several Pesticides to Naiads of Three Species of Stoneflies," *Limnol. Oceanog.*, 13(1):112-117 (1968).

b/ Cope, *op. cit.* (1966).

c/ FWPCA, *op. cit.* (1968).

d/ Jensen, L. D., and A. R. Gaufin, "Effects of Ten Organic Insecticides on Two Species of Stonefly Naiads," *Trans. Am. Fish. Soc.*, 93:27-34 (1964a). In: Li and Fleck (1972).

e/ Gaufin, A. R., L. D. Jensen, A. V. Nebeker, T. Nelson, and R. W. Teel, "The Toxicity of Ten Organic Insecticides to Various Aquatic Invertebrates," *Water Sewage Works*, 12:276-279 (1965). In: Li and Fleck (1972).

f/ Jensen, L. D., and A. R. Gaufin, "Long-Term Effects of Organic Insecticides on Two Species of Stonefly Naiads," *Trans. Am. Fish. Soc.*, 93:357-363 (1964b). In: Li and Fleck (1972).

g/ Sanders, H. O., "Toxicity of Pesticides to the Crustacean *Gammarus lacustris*," U.S. Department of the Interior, Fish and Wildlife Service, Technical Paper No. 25, p. 18 (1969).

Source: Li and Fleck, *op. cit.* (1972).

Ware and Roan (1971)[1] reviewed the literature on the interactions of pesticides with aquatic microorganisms and plankton. A brief section dealing with organophosphate insecticides contains little specific information on malathion.

Moore (1970)[2] and Poorman (1973)[3] investigated the effects of malathion on growth and survival of the photosynthetic microorganisms *Euglena gracilis*. In Moore's tests, malathion inhibited the growth rate of the organism only at the highest rate tested, 7.25 ppm. Poorman found that malathion at 50 and 100 ppm depressed the growth rate of *E. gracilis* only to a small extent during a 24-hr exposure. When the organism was exposed to malathion for 7 days, there was considerable growth stimulation as compared to untreated controls. The results indicate that malathion is not likely to adversely affect *E. gracilis* under field conditions. Lazaroff (1967)[4] also found that malathion did not adversely affect freshwater algae. He employed an assay system based on the inhibition of motility of *E. gracilis*.

Lewis et al. (1974),[5] Paris et al. (1974),[6] and Paris and Lewis (1974)[7] recently reported on the interactions between malathion and a water fungus (*Aspergillus oryzae*) and a heterogeneous population of aquatic bacteria. A. oryzae was isolated from a local pond. Malathion was rapidly removed from water by the fungus, and approximately 97% of the malathion quantity removed was converted to β-malathion monoacid. However, no fungal growth was observed during the experiment. A bacterial culture was isolated from river water and enriched by a culture technique. Members of the bacterial population included Flavobacterium meningosepticum, Xanthomonas sp., Comamonas terrigeri, and Pseudomonas cepacia. This population was capable of utilizing malathion as the sole carbon source. The major metabolite identified was again β-malathion monoacid. However, the malathion uptake speed per unit dry weight of cell material for equivalent malathion concentrations was approximately 5,000 times faster with the bacteria than with the fungus.

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[1] Ware, G. W., and C. C. Roan, "Interaction of Pesticides with Aquatic Microorganisms and Plankton," *Residue Rev.*, 33:15-45 (1971).

[2] Moore, R. B., "Effects of Pesticides on Growth and Survival of *Euglena gracilis* Z.," *Bull. Environ. Contam. Toxicol.*, 5(3):226-230 (1970).

[3] Poorman, A. E., "Effects of Pesticides on *Euglena gracilis*. I. Growth Studies," *Bull. Environ. Contam. Toxicol.*, 10(1):25-28 (1973).

[4] Lazaroff, N., "Algal Response to Pesticide Pollutants," *Bacteriol. Proc.*, CI:48 (1967).

[5] Lewis, D. L., D. F. Paris, and G. L. Baughman, "Uptake and Transformation of Malathion by a Fungus, *Aspergillus oryzae*, Isolated from a Freshwater Pond," submitted to *Appl. Microbiol.* (1974).

[6] Paris, D. F., D. L. Lewis, and G. L. Baughman, "Rates of Degradation of Malathion," unpublished manuscript, submitted to *Environ. Sci. Technol.* (1974).

[7] Paris, D. F., and D. L. Lewis, "Rates and Products of Degradation of Malathion by Bacteria and Fungi from Aquatic Systems," presented at the 167th National Meeting of the American Chemical Society, Division of Pesticide Chemistry, Los Angeles, California (1974).

Several investigators have dealt with the effects of malathion on microorganisms from waste treatment systems. Steelman et al. (1967)[1/] determined the toxicity of malathion and several other insecticides applied at concentrations ranging from 0.1 to 5.0% to bacterial populations in waste disposal lagoons. Waste disposal lagoon water was obtained from the Louisiana State University Poultry Farm. The LD_{50} of malathion to the (unidentified) bacteria in the system after 24-hr exposure was 0.4%, the LD_{90} was 2.35%. Some of the other insecticides tested under the same conditions were more, others were less toxic to the bacteria. When the lagoon water was treated with malathion at 1 ppm, bacterial mortality was 0.83% after 24 hr, zero after 48 hr. The authors conclude that malathion at 1 ppm (the concentration that might be used to control mosquito breeding in waste disposal lagoons) would not cause functional disruption of the lagoon process.

Christie (1969)[2/] treated algal suspensions from a waste stabilization pond with malathion at the rate of 100 ppm. At this rate, algal counts were reduced to less than 45% of untreated controls. At a concentration of less than 100 ppm, malathion did not inhibit Chlorella pyrenoidosa cultures. After 7 days contact of a Chlorella culture with malathion, 67% of the insecticide was recovered. The author believes

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[1/] Steelman, C. D., A. R. Colmer, L. Cabes, H. T. Barr, and B. A. Tower, "Relative Toxicity of Selected Insecticides to Bacterial Populations in Waste Disposal Lagoons," J. Econ. Entomol., 60(2):467-468 (1967).

[2/] Christie, A. E., "Effects of Insecticides on Algae," Water Sewage Works, 116(5):172-176 (1969).

that malathion at these concentrations would temporarily interfere with the efficiency of oxidation ponds, but that it would be broken down by chemical and metabolic reactions.

Halvorson et al. (1971)[1] developed a procedure to test the biodegradability of insecticides by incubating the chemical in a resting-cell suspension of bacteria from a sewage lagoon. There were 50 ppm of malathion added to a cell suspension containing about 400 million bacterial cells per milliliter. These suspensions were then incubated for up to 8 days under aerobic and anaerobic conditions. Malathion (and other organophosphates) was quickly degraded under these conditions, while several persistent chlorinated hydrocarbon insecticides were metabolized poorly or not at all.

Randall et al. (1967)[2] studied the biodegradation of malathion in activated sludge. When shock loadings of malathion were applied to an activated sludge microbial system, an immediate, nonrecoverable uptake of 20% of the chemical was observed. Microbial systems could assimilate single shock loadings of 100 mg/liter without apparent effect. Such systems can effectively assimilate repeated loadings over prolonged periods of time when sufficient nutrients are present. The toxicity of malathion to mixed aquatic biota depended on the organic material present. A low ratio of malathion to microorganisms stimulated microbial activity, whereas large ratios (1:5 or greater) inhibited respiration. Microbial systems acclimated to malathion had a greater resistance to its toxic effects and were more efficient in utilizing malathion as an energy source. Metabolism was greatly increased when no other substrate was present. The authors conclude that the danger of severe stream pollution problems resulting from malathion is minimal. The insecticide is dissipated by aeration and is subject to microbial degradation. Thus, large concentrations of malathion would not persist in streams for extended periods of time. However, the authors point out possible short-term toxic effects should not be ignored.

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[1] Halvorson, H. M., Jr., M. Ishaque, J. Solomon, Jr., and O. W. Grussendorf, Jr., "A Biodegradability Test for Insecticides," Can. J. Microbiol., 17(5):585-591 (1971).

[2] Randall, C. W., M. Asce, and R. A. Lauderdale, "Biodegradation of Malathion," J. Sanit. Eng. Div., Proc. Amer. Soc. Civil Eng., 93(6):145-156 (1967).

Carter and Graves (1973)[1] studied the toxicity of malathion and several other insecticides to White River crawfish, three species of fish, and bullfrog tadpoles. Crawfish were most sensitive to the insecticides tested, while the bullfrog tadpoles were least sensitive. Malathion was only slightly toxic to all of the test species. Higher animals were less sensitive to the insecticides than lower forms, and responses generally varied considerably according to species.

Both reptiles and amphibians in a malathion-treated (2 lb/acre) watershed area were unaffected by the treatment (Peterle and Giles, 1964[2]). The 24-hr LC_{50} for Fowler's toad tadpoles and chorus frog tadpoles exposed to malathion was 1.9 ppm and 0.56 ppm, respectively (Sanders, 1970[3]).

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[1] Carter, F. L., and J. B. Graves, "Measuring Effects of Insecticides on Aquatic Animals," LA Agr., 16(2):14-15 (1973).

[2] Peterle, T. J., and R. H. Giles, New Tracer Techniques for Evaluating the Effects of an Insecticide on the Ecology of a Forest Fauna, Ohio State Univ. Res. Found. Rep., 435 pages (1964).

[3] Sanders, H. O., "Pesticide Toxicities to Tadpoles of the Western Chorus Frog *Pseudacris triseriata* and Fowler's Toad *Bufo woodhousii fowleri*," Copeia, 2:246-251 (1970).

Coppage (1974)[1] determined the toxicity of malathion to pink shrimp (Penaeus duorarum) in flowing seawater at 28 to 29°C and 18 to 20% salinity. After 24 hr exposure to malathion at the concentration of 14 ppb, 32% of the test animals were dead or affected, and up to 60% inhibition of acetylcholinesterase in the ventral nerve cord was measured.

Hansen et al. (1973)[2] studied the ability of grass shrimp (Palaemonetes pugio) to avoid malathion and several other pesticides at concentrations higher and lower than the 24-hr LC_{50}'s. Under these conditions, shrimp showed no ability to avoid malathion. The authors state that shrimp are less able to avoid, and are more sensitive to, pesticides than fishes.

Eisler and Weinstein (1967)[3] studied changes in metal composition of the Quahaug clam (Mercenaria mercenaria) following exposure to malathion. Adult clams were exposed to graded concentrations of malathion for 96 hr at 20°C and 24% salinity. They were apparently unaffected at the highest level tested, 37,000 ppb of malathion. However, analysis of whole animal and selected tissues of the exposed clams showed consistent changes in levels of Na, K, Mg, Fe, and especially Ca and Zn in comparison to untreated controls. These metal shifts present a means of identifying unfavorable environmental conditions before more obvious morphological or physiological changes occur.

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[1] Coppage, D. L., "Effects of Malathion on Estuarine Organisms," unpublished data (1974).

[2] Hansen, D. J., J. M. Keltner, Jr., and S. Schimmel, "Avoidance of Pesticides by Grass Shrimp (Palaemonetes pugio)," Bull. Environ. Contam. Toxicol., 9(3):129-133 (1973).

[3] Eisler, R., Jr., and M. P. Weinstein, "Changes in Metal Composition of the Quahaug Clam, Mercenaria mercenaria, After Exposure to Insecticides," Chesapeake Science, 8(4):253-258 (1967).

Davis and Hidu (1969)[1] studied the effects of malathion and many other pesticides on the embryonic development of the hard clam (*Mercenaria mercenaria*) and the American oyster (*Crassostrea virginica*) and on their larvae. Most of the chemicals affected embryonic development more than survival or growth of larvae. Malathion was characterized as one of three insecticides which appear to be least lethal for survival of oysters and clams.

Sanders (1970) studied the toxicity of malathion to 4- and 5-week-old tadpoles of Fowler's toad (*Bufo woodhousii fowleri*) in static bioassays at 15.5°C. Under these conditions, the estimated TL_{50} values for malathion were 1.9 mg/liter at 24 hr, 0.5 mg/liter at 48 hr, and 0.42 mg/liter at 96 hr. Some of the other pesticides included in these tests were up to 10 times more toxic than malathion, while the least toxic ones were more than 10 times less toxic.

Ranke-Rybicka (1972)[2] studied the viability of tadpoles of *Rana temporaria* exposed intermittently to malathion at 1.25 mg/liter. Ten percent mortality was recorded in 30-day-old tadpoles. Ranke-Rybicka and Stanislawska (1972)[3] observed changes in periphyton organisms caused by malathion at a concentration of 7.42 mg/liter. Protozoa and rotifers were the most sensitive, algae the most resistant organisms.

Malacea and Ionescu (1969)[4] report that in Rumania, the maximum concentration of malathion allowable in surface waters is 0.0006 mg/liter AI.

Field studies - Kennedy and Walsh (1970) studied the effects of malathion on aquatic invertebrates. Ponds were treated with malathion at 0.02 and 0.002 ppm four times over an 11-week period. In the ponds treated at the lower rate, the total number of aquatic insects was not significantly lower than in the untreated ponds. In the ponds treated at the higher rates, the number of organisms was significantly lower than that in untreated ponds. At both treatment rates, benthic organisms (Chironomidae and mayflies) were significantly reduced in numbers.

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[1] Davis, H. C., and H. Hidu, "Effects of Pesticides on Embryonic Development of Clams and Oysters, and on Survival and Growth of the Larvae," *U.S. Fish Wildl. Serv., Fish Bull.*, 67(2):393-404 (1969).

[2] Ranke-Rybicka, B., "Viability of Tadpoles of *Rana temporaria* Intermittently Exposed to Organophosphorus Pesticides (Phoschlor and Malathion)," *Roez. Panstw. Zakl. Hig.*, 23(3):37 (1972).

[3] Ranke-Rybicka, B., and J. Stanislawska, "Changes in Periphyton Organisms Caused by Organophosphorus Pesticides (Malathion, Phoschlor)," *Roez. Panstw. Zakl. Hig.*, 23(2):137-146 (1972).

[4] Malacea, I., and M. Ionescu, "Toxicity of Some Organophosphorus Insecticides to Aquatic Organisms," *Hydrobiologia*, 10:31-41 (1969).

Wall and Marganian (1971)[1] studied the effects of malathion (and several other insecticides) applied against mosquitoes on the nontarget fauna. Malathion was applied as a granular formulation (concentration and rate not given) to 0.04 and 0.12 acre intertidal sand plots. Malathion was less effective as a mosquito larvicide than some of the other insecticides tested. None of the tested pesticides (including malathion) appeared to directly affect bivalves or plankton.

Butcher et al. (1964)[2] reported on a stream sampling study conducted to obtain evidence of possible pesticide effects on aquatic arthropods. Malathion from an 8.0-lb AI/gal formulation was applied by air at the rate of 1 lb AI in 1 gal. of water per acre to an 80-acre block of land containing representative cover types and a small stream traversing a considerable portion of it. The level of sampling intensity in this study was not sufficient to clearly differentiate between possible effects of the insecticide treatment and normal seasonal population fluctuations, and/or reinfestation by multiple generation forms (e.g., chironomids). With these reservations, the arthropod fauna of the study area did not appear to be altered qualitatively or quantitatively as a result of the treatment. Catastrophic effects on nontarget organisms would have been demonstrated by the observation methods employed, and no such effects were evident in the two most numerous taxa, amphipods and chironomids.

As reported by Giles (1970), an application of malathion at the rate of 0.7 lb AI/acre to a forested watershed in Ohio resulted in a marked reduction of the numbers of aquatic insects in the stream environment, but recovery occurred rapidly. Reptiles and amphibians were unaffected.

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[1] Wall, J., and V. M. Marganian, Jr., "Control of Culicoides melleus (Coq) (Diptera:Ceratopogonidae) with Granular Organophosphorus Pesticides, and the Direct Effect on Other Fauna," Mosquito News, 31(2):209-214 (1971).

[2] Butcher, J. W., J. Truchan, R. Wilson, and J. Fahey, "Streams Sampling for Evidence of Pesticide Effects on Aquatic Arthropods," Proc. N.C. Branch, Entomol. Soc. Amer., 19:130-132 (1964).

When malathion was used in three grasshopper control projects in Montana (Morton, 1966), Wyoming (Henderson, 1967a), and Utah (Henderson, 1967b), somewhat varying effects on lower aquatic organisms were observed. In the Montana project, there was no significant effect on the aquatic bottom fauna from the treatment. However, there was a very significant increase in the number of "drift" organisms that appeared 5 hr after spraying. In the Wyoming project, there were minimal effects on aquatic life, and drift organisms showed only a small to moderate increase at any time during the spray period. Bottom animal samples indicated some reduction in fish food organisms, mainly stonefly nymphs. In the Utah project, there was no significant increase in drift organisms after the malathion application. However, there was almost complete mortality of mayfly, stonefly and caddisfly larvae. These differences in the effects of the malathion treatments on the number of drift organisms and on the bottom fauna are largely explained by the different nature and flow rates of the streams in the respective study areas.

Tagatz et al. (1974) studied the effects of ground applications of malathion on salt-marsh environments in northwestern Florida. Malathion was applied repeatedly as a thermal fog at 6 oz/acre, and as a ULV aerosol spray at 0.64 fl oz/acre in a manner typical of mosquito control operations. Malathion did not result in deaths among confined blue crabs (Callinectes sapidus), grass shrimp (Palaemonetes vulgaris and P. pugio), or pink shrimp (Penaeus duorarum). Neither the confined animals nor the snail (Littorina irrorata) contained detectable amounts of malathion on analysis.

The extensive data reviewed in this subsection indicate that malathion is very toxic to aquatic insects, toxic to the lower aquatic fauna, and relatively nontoxic to the lower aquatic flora. A number of aquatic microorganisms degrade malathion. In cases where disruptions of the aquatic fauna occur following application of malathion at insecticidally effective rates, the preapplication balance appears to return rapidly, probably due to the rapid degradation of the insecticide under field conditions.

Effects on Wildlife

Laboratory Studies - The acute toxicity of malathion to avian species has not been as extensively studied as some other pesticides. The acute oral LD_{50} of malathion to female mallard ducks is 1,485 mg/kg (Tucker and Crabtree, 1970[1]). The subacute oral toxicity of malathion has been studied in more species than the acute oral, and the subacute oral toxicity is summarized in Table 25. The subacute studies revealed that the potential hazard to avian species tested is very low. Malathion ULV at one and 10 times the normal application rate did not produce any detectable neurotoxic symptoms to bobwhite quail treated 20 times within a 34-day period. Food consumption was normal and cholinesterase activity was not depressed (Joseph et al., 1972).

The acute toxicity symptoms of malathion poisoning in avian species consist of ataxia, walking high on toes, wing drop, falling stiffly with wings spread, tenesmus, foamy salivation and tremors (Tucker and Crabtree, 1970).

Field Studies - Malathion was applied to about 4,300 acres of meadow and rolling grasslands in the Dixie National Forest, Utah, at the rate of about 8 fl oz/acre (Henderson, 1967b), as already mentioned in the preceding subsection. Many species of birds and some mammals, including deer, were relatively abundant in the treated area. No specific studies were conducted, but project members reported no adverse effects or behavioral changes in any of the wildlife species. McEwen et al. (1972)[2] studied the effects on wildlife of malathion (and other insecticides) at rates required for grasshopper control in test plots on short-grass range in Montana, New Mexico, and Wyoming. Effects on wildlife were determined by way of bird and small mammals censuses, carcass counts, and residue analyses. Malathion applied at 6.8 oz AI/acre did not result in any observable direct effects on wildlife.

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[1] Tucker, R. K., and D. G. Crabtree, Handbook of Toxicity of Pesticides to Wildlife, Bureau of Sport Fisheries and Wildlife, Denver Wildlife Research Center, Resource Publication No. 84, pp. 76-77 (1970).

[2] McEwen, L. C., C. E. Knittle, and M. L. Richmond, "Wildlife Effects from Grasshopper Insecticides Sprayed on Short-Grass Range," J. Range Mgmt., 25(3):188-194 (1972).

Table 24. SUBACUTE TOXICITY OF MALATHION TO AVIAN SPECIES

Species	5-Day median lethal concentration (LC_{50})* (ppm)	References
Bobwhite quail (*Colinus virginianus*)	3,497	a/
Japanese quail (*Coturnix japonica*)	2,128	a/
Pheasant (*Phasianus colchicus*)	4,320	a/
Mallard duck (*Anas platyrhynchos*)	> 5,000	a/

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* LC_{50}: ppm compound (AI) in ad libitum diet expected to produce 50% mortality in 8 days (5 days on toxic diet followed by 3 of untreated diet).

a/ Heath, R. G., J. W. Spann, E. F. Hill, and J. F. Kreitzer, "Comparative Dietary Toxicities of Pesticides to Birds," U.S. Bureau of Sport Fisheries and Wildlife, Special Scientific Report--Wildlife No. 152, pp. 1-40 (1972).

Parsons and Davis (1971)[1] investigated the short-term effects of aerial spraying of malathion on quail, migratory birds, and nongame birds using cover or prairie lakes adjacent to cotton fields treated with insecticides for the control of the boll weevil. No bird mortality or other evidence of direct adverse effects were observed on any of the land or water areas sprayed with malathion at the rate of 12 to 16 fl oz/acre. Quail which were caged and exposed to each spray in the field and fed on sprayed feed showed small but nonsignificant differences in growth rates compared to untreated birds.

Joseph et al. (1972) reported that mice and quail did not exhibit any poisoning symptoms when they were exposed to ground applications of ULV malathion at the recommended rate (1.5 fl oz/min), and a second rate 10 times that concentration. Twenty applications were made over a 34-day period. Tests for red cell cholinesterase inhibition 24 hr after the last exposure were negative in both species.

In the study by Giles (1970) already mentioned above, wildlife species were observed following application of malathion at the rate of 0.7 lb/acre to a forested watershed in Ohio. Birds in the treated area appeared to be noticeably quiet for 2 days after spraying, but no lasting effects were noted. Populations of mice and chipmunks appeared to be reduced by at least 30%. Shrews and larger mammals were unaffected.

Culley and Applegate (1967)[2] determined insecticide residues in representative species of reptiles, birds, and wild mammals from the Presidio Valley in Texas. This valley has approximately 384,000 acres of land, of which 2,900 acres are under cultivation and pesticide treatments. The valley is surrounded by mountains and represents a point source of insecticide application within a large isolated area. Specimens for analysis were obtained by shooting or trapping from insecticide-exposed and nonexposed areas. Under a Federal program, a total of 17,640 lb of malathion were applied in seven low-volume, high-concentration sprays. No malathion residues were detected in any of the samples analyzed, including lizard tail muscle, brain tissue, liver, coelom fat, and stomach contents;

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[1] Parsons, J. K., and B. D. Davis, "The Effects on Quail, Migratory Birds, and Nongame Birds from Application of Malathion and Other Insecticides," Tech. Series No. 8, Texas Parks and Wildl. Dept., pp. 1-20 (1971).

[2] Culley, D. C., and H. G. Applegate, "Insecticide Concentrations in Wildlife at Presidio, Texas," Pest Monit. J., 1(2):21-28 (1967).

sparrow breast muscle, brains, liver and gizzards; and in leg muscles and livers of pocket mice and kangaroo rats. Some of these samples were obtained within 6 weeks after the malathion applications. The authors concluded that malathion residues rapidly disappeared from the ecosystem studied.

Bejer-Petersen et al. (1972)[1/] studied the effects of spray treatments of malathion and other insecticides in forests on birds living in nest boxes. Malathion spraying (rate not given in abstract) was carried out in 1965 and in 1967 at a time when nestlings of Parus major and P. ater were most numerous. The malathion treatments did not significantly affect the birds' breeding success, nor result in loss of nestlings. However, reduced brain cholinesterase activity was observed in one or two of the broods of each species.

The studies reviewed in this subsection indicate that many species of wildlife exposed to malathion applications at dosage rates required for insect control tolerate the insecticide rather well. Effects on wildlife outside of target areas appear to be minimal. Furthermore, as reported in the subsection on "Production and Use," malathion is registered, recommended and used for the control of various insects, mites, and ticks directly on animals, including cattle, horses, hogs, sheep, goats, dogs, cats, chickens, ducks, geese, and turkeys. These facts indicate that malathion has a favorable safety margin between target pests on the one hand, and host and nontarget higher terrestrial animals on the other.

Effects on Beneficial Insects

Bees - Anderson and Tuft (1952)[2/] determined the toxicity of many different pesticides to honeybees in laboratory experiments. Malathion was among those that were most toxic to the bees; 100% were killed in a few minutes. In field tests by Anderson and Atkins (1958),[3/] malathion was rated as "moderately toxic" to honeybees.

[1/] Bejer-Petersen, B., R. R. Hermansen, and M. Weihe, "On the Effects of Insecticide Sprayings in Forests on Birds Living in Nest Boxes," Dan. Ornithol. Foren. Tidsskr., 66(1,2):30-50 (1972).

[2/] Anderson, L. D., and T. O. Tuft, "Toxicity of Several New Insecticides to Honey Bees," J. Econ. Entomol., 45:466-469 (1952).

[3/] Anderson, L. D., and E. L. Atkins, Jr., "Toxicity of Pesticides to Honey Bees in Laboratory and Field Tests in Southern California, 1955-1956," J. Econ. Entomol., 51:103-108 (1958).

Johansen et al. (1965)[1] investigated the effects on bees of a ULV application of malathion on blooming alfalfa at the rate of 10 oz/acre. Malathion killed field bees for at least 4 days. Bees caged on treated foliage also exhibited above normal mortality for 4 days. There was no perceptible fumigant action. Bees from colonies 2.5 miles away that foraged in the treated area were killed. Living hive bees became contaminated with malathion residues. On the fifth day after treatment, malathion residues on alfalfa foliage declined markedly, apparently due to rainfalls which began on the fourth day. Covering bees for 2 days with wet burlap tarpaulins did not afford sufficient protection. The authors emphasize that the malathion ULV application gave more than four times the residual action usually encountered following dilute malathion applications.

Levin et al. (1968)[2] also reported unexpected injury to bees from malathion ULV applications in Wyoming for the control of grasshoppers. Large numbers of honeybees were killed, and about 600 colonies were seriously damaged following a malathion ULV application at the rate of 8 fl oz/acre. Malathion residues were detected in alfalfa (12 to 29 ppm), in pollen (0.43 to 11.1 ppm), and in dead bees (less than 0.01 to 0.37 ppm) for as long as 8 days after the application. The authors conclude that undiluted malathion at this rate must be considered dangerously toxic to honeybees.

Johansen (1972)[3] studied the toxicity of field-weathered residues of malathion and other insecticides to different species of bees. Malathion from a 5-lb/gal emulsifiable liquid was applied to alfalfa at the rate of 1.0 lb AI/acre. Three kinds of bees were exposed to the malathion residues 10 hr after application. Bee mortality was determined after 24 hr and was 100% in alfalfa leafcutter bees (*Megachile rotundata*) and honeybees (*Apis mellifera*); and 47% in alkali bees (*Nomia melanderi*).

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[1] Johansen, C. A., M. D. Levin, J. D. Eves, W. R. Forsyth, H. B. Busdicker, D. S. Jackson, and L. I. Butler, "Bee Poisoning Hazard of Undiluted Malathion Applied to Alfalfa in Bloom," *Washington Agr. Exp. Sta. Circular No. 455* (1965).

[2] Levin, M. D., W. B. Forsyth, G. L. Fairbrother, and F. B. Skinner, "Impact on Colonies of Honey Bees for Ultra-Low-Volume (Undiluted) Malathion Applied for Control of Grasshoppers," *J. Econ. Entomol.*, 61(1):58-62 (1968).

[3] Johansen, C. A., "Toxicity of Field-Weathered Insecticide Residues to Four Kinds of Bees," *Environ. Entomol.*, 1(3):393-394 (1972).

Johansen and Davis (1972)[1] compared the toxicity of malathion and other insecticides against the western yellow jacket (Vespula pennsylvanica) and the honeybee (A. mellifera). Malathion (and most of the other insecticides studied) was somewhat more toxic to the western yellow jacket (LD_{50} 3.3 μg/g) than to the honeybee (LD_{50} 5.5 μg/g).

Mayland and Burkhardt (1970)[2] exposed honeybees to surfaces of plastic, glass, alfalfa leaves, rhubarb leaves, filter paper, and soil treated with malathion (and, in separate tests, with other insecticides). There were sufficient differences in bee mortalities resulting from exposure to the different insecticide-treated surfaces to indicate that the surface must be taken into consideration in studies on the effects of insecticides on bees in the laboratory. In all test series, malathion was highly toxic to bees. Three-week-old bees were least susceptible to the insecticides in comparison to other age groups.

Entomologists from abroad report generally similar observations on the toxicity of malathion to honeybees. Beran and Neururer (1955)[3] determined the toxicity of malathion and other insecticides to bees by oral and tarsal application, and by exposing bees to insecticide-impregnated filter paper. By all three methods of application, malathion was highly toxic to the bees. Greenhouse and field tests conducted over a 5-year period also indicated that malathion is toxic to bees (Beran and Neururer, 1956[4]). By contrast, Gorecki (1973)[5] rates malathion among the number of "organophosphorus insecticides safe to bees."

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[1] Johansen, C. A., and H. G. Davis, "Toxicity of Nine Insecticides to the Western Yellowjacket," J. Econ. Entomol., 65(1):40-42 (1972).

[2] Mayland, P. G., and C. C. Burkhardt, "Honey Bee Mortality as Related to Insecticide-Treated Surface and Bee Age," J. Econ. Entomol., 63(5):1437-1439 (October 1970).

[3] Beran, F., and J. Neururer, "The Action of Plant Protectants on the Honey Bee (Apis mellifera). I. Toxicity of Plant Protectants to Bees," Pflanzenschutz Ber., 15:97-147 (1955).

[4] Beran, F., and J. Neuruer, "Actions of Plant Protectants on the Honey Bee (Apis mellifera). II. Toxicity of Plant-Protection Agency to Bees," Pflanzenschutz Ber., 17:113-190 (1956).

[5] Gorecki, K., "Harmful Effects of Insecticides Used in Poland on Apis mellifica (Honey Bees)," Pol. Pismo Entomol., 43(1):201-210 (1973).

Markosyan (1968)[1] and Wiess (1957, 1958a, 1958b)[2,3,4] found malathion to be very toxic to bees, based on a variety of laboratory and field tests.

Malathion labels carry the notice, "This product is highly toxic to bees exposed to direct treatment." In the light of the laboratory and field data reported above, this warning appears to be highly warranted, especially in the case of ULV applications.

Parasites and Predators - The importance of naturally occurring parasites and predators of insect and mite pests in suppressing these pests and reducing or preventing economic damage has been increasingly recognized in recent years. A number of investigators have studied the effects of malathion on such parasites and predators.

Harries and Valcarce (1955)[5] studied the toxicity of malathion 5% dust applied to sugar beet plants on which three species of beneficial insects were confined for 24 hr in cellulose acetate cages. The malathion treatment resulted in the following mortalities: 90% in adult convergent lady bettles (*Hippodamia convergens*), 47% in striped collops (*Collops vittatus*), and 100% in spotted lady beetles (*Coleomegilla maculata*). Malathion was among the insecticides most toxic to these beneficial insects under the experimental conditions studied.

Burke (1959)[6] investigated the toxicity of several insecticides including malathion to beneficial cotton insects. Adult *Orius insidiosus*

1/ Markosyan, Z. K., "Effects of Pesticides on Bees Under Hothouse Conditions," *Mater. Sess. Zakavkaz. Sov. Koord. Nauch.-Issled. Rab. Zushch. Rast.*, pp. 688-690 (1968).

2/ Wiese, I. H., "Toxicity of Modern Insecticides to the South African Honey Bee," *S. African Bee J.*, 32:2,7,9-10 and 3,6-7,9-10 (1957).

3/ Wiese, I. H., "The Toxicity of Modern Insecticides to the South African Honey Bee," *African Beekeeping*, 1:14-15 (1958a).

4/ Wiese, I. H., "The Toxicity of Modern Insecticides to the South African Honey Bee," *S. African Bee J.*, 32:4,5,7; 5,9-11 and 6,10-11 (1958b).

5/ Harries, F. H., and A. C. Valcarce, "Laboratory Tests of the Effect of Insecticides on Some Beneficial Insects," *J. Econ. Entomol.*, 48:614 (1955).

6/ Burke, H. R., "Toxicity of Several Insecticides to Two Species of Beneficial Insects on Cotton," *J. Econ. Entomol.*, 52:616-618 (1959).

were confined to insecticide-treated cotton plants for 2 days. Under these conditions, malathion was one of the insecticides most toxic to this species.

Lingren et al. (1972)[1] studied the toxicity of malathion and other insecticides to two species of parasitic wasps, Apanteles marginiventris and Campoletis perdistinctus. The LD_{50} of malathion applied topically to adult male C. perdistinctus was 0.0064 µg/insect. When malathion was applied topically to cocoons of C. perdistinctus, 10% cocoon mortality occurred at the rate of 0.64 µg/cocoon, while 0.064 µg/cocoon produced 6% cocoon mortality. In these tests, malathion was among the more toxic insecticides.

Ridgway et al. (1974)[2] studied the effects of malathion applied at 0.25 lb/acre from a 96% AI ULV formulation to beneficial insects on cotton. In laboratory and field tests malathion was highly toxic to green lacewing larvae (Chrysopa spp.), the adult big-eyed bug (Geocoris punctipes), and the adult lady beetle (Hippodamia convergens).

Hamilton and Kieckhefer (1969)[3] investigated the toxicity of malathion to predators of the English grain aphid (Macrosiphum avenae). Adult and larval forms of the three most numerous and ubiquitous predators of cereal aphids in South Dakota, Hippodamia convergens (the convergent lady beetle), Nabis americoferus, and Chrysopa carnea were field-collected for laboratory mortality tests. By topical application to adults, the LD_{50} of malathion to the aphid 4 hr post treatment was 3.6 µg/g, while it ranged from 68 to 830 µg/g to adults, nymphs and larvae of the three predators. LC_{50} values of malathion to the same insects were determined by exposing the insects to 4-hr-old deposits of appropriate concentrations. Again, the LC_{50} values of malathion to the predators were much higher than to the aphid.

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[1] Lingren, P. D., D. A. Wolfenbarger, J. B. Nosky, and M. Diaz, Jr., "Response of Campoletis perdistinctus and Apanteles marginiventris to Insecticides," J. Econ. Entomol., 65(5):1295-1299 (1972).

[2] Ridgway, R. L., C. B. Cowan, and J. R. Cage, unpublished data (personal communication) (1974).

[3] Hamilton, E. W., and R. W. Kieckhefer, "Toxicity of Malathion and Parathion to Predators of the English Grain Aphid," J. Econ. Entomol., 62(5):1190-1192 (October 1969).

Teetes (1972)[1] reported that when insecticides were applied to grain sorghum for the control of the green bug (Schizaphis graminum), populations of beneficial insects including lady beetles (hippodamia convergens) and green lacewings (Chrysopa spp.), declined. One of the highest percentages of mortality among the beneficial species was seen following applications of malathion. Malathion at 0.5 and 0.1 lb AI/acre showed one of the greatest residual effects on the beneficial insects among all insecticides studies.

Johansen et al. (1965) observed that an application of malathion ULV to blooming alfalfa at the rate of 10 oz/acre resulted in reduction of lady beetle populations, while nabid and anthocorid bugs appeared to be unaffected.

In studies on the effects of insecticides on the fauna of apple orchards in Nova Scotia (MacPhee and Sanford, 1956[2]), malathion had drastic adverse effects on predators and parasites.

Hill et al. (1971)[3] reported on the effects of aerial ULV applications of malathion for mosquito control at the rate of 0.2 lb AI/acre in Texas. Nine malathion ULV applications were made on three towns. Nontarget insect counts were obtained by use of sweep nets and a vehicle-mounted trap. The insect orders Homoptera and Hemiptera declined during the treatment period, whereas other insect orders including Diptera (with the exception of Culicidae) were not affected. The authors concluded from their observations that low-volume aerial applications of malathion for mosquito control are sufficiently safe to the nontarget fauna to justify the product's use, although beekeepers should be notified to cover beehives during application.

A number of reports from abroad generally confirm that there is little, if any, selectivity between the toxicity of malathion to target insects and to beneficial parasites and predators occurring on the same host plant. Manser and Bennett (1962-1963)[1] found that malathion would cause mortality of *Lixophaga diatraeae*, a parasite of the sugarcane borer (*Diatraea saccharalis*) if present in the field during application. Because of the short residual action of malathion, the authors believe that reduction in the parasite populations would only be temporary.

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[1] Teetes, G. L., "Differential Toxicity of Standard and Reduced Rates of Insecticides to Greenbugs and Certain Beneficial Insects," Tex. Agr. Exp. Sta., Progress Report No. PR-3041, 9 pages (1972).

[2] MacPhee, A. W., and K. H. Sanford, "Influence of Spray Programs on the Fauna of Apple Orchards in Nova Scotia. X. Effects on Some Beneficial Arthropods," Can. Entomol., 88:631-634 (1956).

[3] Hill, E. F., D. A. Eliason, and J. W. Kilpatric, "Effects of Ultra-Low Volume Applications of Malathion in Hale County, Texas," J. Med. Entomol., 8(2):173-179 (1971).

Pradhan et al. (1968)[2] found that malathion was more toxic to an aphid predator, *Coccinella septempunctata*, than to the mustard aphid (*Lipaphis erysimi*). Satpathy et al. (1968)[3] studied the toxicity of malathion and other insecticides to the aphid predator *Chilomenes sexmaculata* by feeding adult beetles with insecticide-poisoned aphids. Malathion was among the insecticides most toxic to the predator. Teotia and Tiwari (1972)[4] also found malathion to be among the insecticides most toxic to the aphid predator *Coccinella septempunctata*. Kowalska and Szczepanska (1971)[5] described malathion as among those insecticides showing varying but persistent degrees of toxicity against such natural enemies of aphids as lacewings, lady beetles, and *Hymenoptera* (*Encarsia formosa* and *Phytoseiulus persimilis*), introduced into Poland specifically for use as entomophagous agents. Abdelrahman (1973)[6] reported that the natural enemies of the California red scale (*Aonidiella aurantii*) were considerably more susceptible to malathion than female red scales in the second moult state. In this state, the red scale was 707 times more tolerant to malathion than Aphytis melinus; 294 times more tolerant than Comperiella bifasciata, and 10 times more tolerant than Lindorus lophanthae. (Results of tests indicate malathion is not suitable in an integrated program for the control of this citrus pest.)

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[1] Manser, P. D., and F. D. Bennett, "Possible Effects of the Application of Malathion on the Small Moth Borer, *Diatraea saccharalis* (F), and Its Parasite *Lizophaga diatraeae* (Tns.) in Jamaica," *Bull. Entomol. Res.*, 53:75-82 (1962/1963).

[2] Pradhan, S., M. G. Jotwani, Sarup, Prakash, "Bioassay of Different Insecticides on the Important Insect Pests and Predators of Agricultural Importance," *Pest. Symp.*, pp. 92-103 (1968).

[3] Satpathy, J. M., G. K. Padhi, and D. N. Dutta, "Toxicity of Eight Insecticides to the Coccinellid Predator *Chilomenes sexmaculata*," *Indian J. Entomol.*, 30(1):130-132 (1968).

[4] Teotia, T. P. S., and G. C. Tiwari, "Toxicity of Some Important Insecticides to the Coccinellid Predator, *Coccinella septempunctata*," *Labdev*, Part B, 10(1):17-18 (1972).

[5] Kowalska, T., and K. Szczepanska, "Toxicity to Entomophages of Some Pesticides Used in Poland," *Biul. Inst. Ochr. Rosl.*, 50:179-194 (1971).

[6] Abdelrahman, I., "Toxicity of Malathion to the Natural Enemies of California Red Scale, *Aonidiella aurantii* (Hemiptera:Diaspididae)," *Aust. J. Agr. Res.*, 24(1):119-133 (1973).

The extensive data summarized in this subsection indicate that in most crop-pest-predator/parasite systems, malathion appears to have little, if any, selective toxicity to pest species. In some instances, it appears to be more toxic to beneficial than to pest insects.

Interactions with Lower Terrestrial Organisms

Reviews - The relationships between insecticides and microorganisms have recently been reviewed by several authors. **Matsumura** and Boush (1971)[1] report that organic phosphate insecticides (including malathion) have thus far not presented serious problems in soils as regards undesirable persistence, nor demonstrated a potential for buildup in food chains. Although considerable variations exist between individual organophosphates, most of them are readily degraded in the soil, mainly by hydrolytic and oxidative means.

Matsumura and Boush also point out that, although several workers have demonstrated in the laboratory that certain microorganisms are able to degrade even the most stable and persistent organic insecticides, it has not as yet been demonstrated whether or not this occurs in nature, or even that these compounds serve as nutritional or energy sources for organisms. "In fact there are no reports as yet that these chemicals have been shown to serve as sole nutritional carbon sources."

Another recent review of the interactions between pesticides (including malathion) and the soil fauna has been presented by Drift (1970).[2]

Laboratory and Field Studies - **Matsumura** and Boush (1966)[3] found that malathion was metabolized quickly by a soil fungus, Trichoderma viride, and a bacterium, Pseudomonas sp., which were isolated from Ohio soils that had been heavily treated with insecticides. The breakdown capabilities of 16 variants of T. viride were studied. Certain colonies from this species had a very marked ability to degrade malathion through the action of one or several carboxylesterase enzymes. Both of these soil organisms occur commonly in many soils and may assist in the elimination of some insecticide residues. Alternatively, the residual toxicity of such insecticides might be extended by a reduction of the populations of these microorganisms in the soil.

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[1] Matsumura, F., and G. M. Boush, "Metabolism of Insecticides by Microorganisms," Soil Biochem., 2:320-336, Marcel Dekker, New York (1971).

[2] Drift, J., "Pesticides and Soil Fauna," Meded. Rijksfac. Landbouwwetensch., Gent, 35(2):707-716 (1970).

[3] Matsumura, F., and G. M. Boush, "Malathion Degradation by Trichoderma viride and a Pseudomonas Species," Science, 153(3741):1278-1280 (1966).

Garretson and San Clemente (1968)[1] studied the interactions between malathion (and several other insecticides) and nitrifying bacteria. Of all chemicals tested, malathion was the least toxic to Nitrobacter agilis; at the highest rate tested, 1,000 µg/ml, it only caused some delayed nitrification. However, malathion caused complete inhibition of Nitrosomonas europaea at 10 µg/ml. The authors emphasized that these laboratory findings should not be extrapolated to field conditions.

Walker and Stojanovic (1974)[2] isolated 18 soil bacteria and found that, of these, five were capable of utilizing the malathion molecule as a substrate. Degradation of added malathion ranged from 47 to 95%. An Arthrobacter species was the most efficient malathion utilizer; it degraded the chemical to its half-ester, dicarboxylic acid, and several other identified and unidentified metabolites.

Anderson (1971)[3] investigated the capacity of several fungi isolated from an agricultural loam soil to degrade DDT. In shake cultures, Mucor alternans partially degraded DDT in 2 to 4 days into two water-soluble metabolites. Malathion did not affect the growth of the fungus or its degradation of DDT.

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[1] Garretson, A. L., and C. L. San Clemente, "Inhibition of Nitrifying Chemolithotrophic Bacteria by Several Insecticides," J. Econ. Entomol., 61(1):285-288 (1968).

[2] Walker, W. W., and B. J. Stojanovic, "Malathion Degradation by an Arthrobacter Species," J. Environ. Qual., 3(1):4-10 (1974).

[3] Anderson, J. P. E., "Factors Influencing Insecticide Degradation by a Soil Fungus, Mucor alternans," Diss. Abstr. Int., 32(6):3114B-3115B (1971).

Mostafa et al. (1972a)[1] found that two soil microorganisms, *Rhizobium leguminosarum* and *R. trifolii*, metabolized ^{32}P-labeled malathion at the rate of 67 and 87%, respectively, in 1 week. Several malathion hydrolysis products were identified. The nature of the breakdown products indicates the involvement of a very active carboxylesterase system plus, probably, one or several additional enzymes. In a related study, Mostafa et al. (1972b)[2] found that the fungi *Penicillium notatum* and *Aspergillus niger* metabolized 76 and 59%, respectively, of ^{32}P-labeled malathion into water-soluble metabolites within 10 days. Smaller fractions (7 and 25%, respectively) were metabolized into $CHCl_3$-soluble compounds.

Sethunathan and Yoshida (1972)[3] found that malathion was not degraded by a cell-free extract of a species of Flavobacterium isolated from water of a rice field previously treated with diazinon. Several other phosphate insecticides having a P-O-C bond were rapidly degraded by this extract.)

In a field study in which malathion was applied to a forested watershed in Ohio at the rate of 0.7 lb AI/acre (Giles, 1970), no effects from the insecticide treatment were observed on bacteria or fungi. Soil microarthropods were affected for a short time, but earthworms and snails showed no adverse symptoms.

Getzin and Rosefield (1968, 1971)[4,5] and Satyanarayana and Getzin (1973)[6] extracted a heat-labile, water-soluble substance that accelerated the degradation of malathion from nonautoclaved and radiation-sterilized soil. The substance was destroyed by heating soil suspensions for 10 min at 90°C, but most of its activity was retained in soils held at 25°C for 2 or 3 months after radiation sterilization. In subsequent tests, the substance was purified and characterized. Unlike the animal enzymes which hydrolyze malathion, the preparation catalyzed the hydrolysis of aromatic, but not aliphatic esters. The substance exhibited all properties essential to stability in the soil, including thermal stability, resistance to proteolytic attack, tolerance to pH extremes, apparent lack of requirement for cofactors, and tolerance to heavy metals and common enzyme inhibitors. The authors suggest a carbohydrate-protein structure and propose that this cell-free soil enzyme should be an excellent tool for investigating enzymatic biological transformations in soil.

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[1] Mostafa, I. Y., I. M. I. Fakhr, M. R. E. Bahig, and Y. A. El-Zawahry, "Metabolism of Organophosphorus Insecticides. XIII. Degradation of Malathion by *Rhizobium* spp.," *Arch. Mikrobiol.*, 86(3):221-224 (1972a).

[2] Mostafa, I. Y., M. R. E. Bahig, I. M. I. Fakhr, and Y. Adam, "Metabolism of Organophosphorus Insecticides. XIV. Malathion Breakdown by Soil Fungi," *Z. Naturforsch.*, B 27(9):115-116 (1972b).

[3] Sethunathan, N., and T. Yoshida, "Conversion of Parathion to Paranitrophenol by Diazinon-Degrading Bacterium," *Proc. Inst. Environ. Sci. Ann. Tech. Meet.*, 18:255-257 (1972).

[4] Getzin, L. W., and I. Rosefield, "Organophosphorus Insecticide Degradation by Heat-Labile Substances in Soil," *J. Agr. Food Chem.*, 16(4):598-601 (1968).

[5] Getzin, L. W., and I. Rosefield, "Partial Purification and Properties of a Soil Enzyme That Degrades the Insecticide Malathion," *Biochem. Biophys. Acta*, 235(3):442-453 (1971).

[6] Satyanarayana, T., and L. W. Getzin, "Properties of a Stable Cell-Free Esterase from Soil," *Biochem.*, 12(8):1566-1572 (1973).

Kutches (1970)[1/] and Kutches et al. (1970)[2/] studied the effects of malathion and 11 other pesticides on the microbial activity of sheep rumen liquor _in vitro_. Dry matter disappearance, volatile fatty acid production, and alterations in rumen ciliated protozoal numbers were the criteria measured. Relatively high concentrations (500 µg/ml) of malathion (and of the other pesticides) were tolerated by rumen microorganisms without deleterious effects on rumen function. The authors conclude that the concentrations of pesticides that might be ingested by ruminants by way of contaminated feedstuffs would have no or negligible effects on rumen digestibility or other rumen functions. Pesticide residues that might be found on contaminated feedstuffs would be expected to be much lower than those studied.

Nestor (1972)[3/] found that malathion inhibited the growth of gram-positive bacteria at concentrations ranging from 5 to 100 µg/liter. The growth of gram-negative bacteria was inhibited to a lesser degree. Xylene and emulsifiers used in insecticidal formulations exhibited a less marked bactericidal effect. Malathion had a certain bacteriostatic effect against _Baccillus anthracis_ and enterococci.

[1/] Kutches, A. J., "Influence of Pesticides on Rumen Microbial Metabolism," _Diss. Abstr. Int._, 31(5):2387B-2388B (1970).

[2/] Kutches, A. J., D. C. Church, and F. L. Duryee, "Toxicological Effects of Pesticides on Rumen Function _in vitro_," _J. Agr. Food Chem._, 18(3):430-433 (1970).

[3/] Nestor, I., "Influence of Organophosphorus Insecticides of the Malathion and Bromofos Type on Gram-Positive Bacteria," _Igiena_, 20(12):723-730 (1972).

The studies summarized in this subsection indicate that a number of soil microorganisms are capable of degrading malathion. However, no reports were found indicating if and to what extent such processes may occur under field conditions in situ.

Residues in Soil

Laboratory Studies - MacNamara (1969)[1] and MacNamara and Toth (1970)[2] investigated the adsorption and release of malathion, using various saturated clay systems, humic acid, and 10 New Jersey soils (A and B horizons known to be free of organic pesticide contamination). The adsorption of malathion by clay minerals appeared to be related to the cation exchange capacities of the clays. More malathion was adsorbed by potassium-saturated systems than by the calcium-, magnesium- or hydrogen/aluminum-saturated clays. More malathion was adsorbed by the humic acid system than by any of the clay systems. Adsorption was higher in the soils with higher organic matter content. Desorption studies showed that electrolyte solutions either suppressed or had little effect on the release of malathion.

Bowman (1970)[3] and Bowman et al. (1970)[4] studied the effect of water on the adsorption of malathion on five montmorillonite systems. Malathion penetration of the interlayer regions of montmorillonite was very slow, below 30% relative humidity. At relative humidities exceeding 40%, malathion penetrated within minutes and was adsorbed as a double layer. The mechanism of adsorption was through a hydrogen bonding interaction between the carbonyl oxygen atoms and the hydration water shells of the saturating cations. Changes in the hydration status of the clay system produced marked reversible alterations in the spectrum of adsorbed malathion that were believed due to orientation and interaction effects. No degradation of adsorbed malathion was observed.

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[1] MacNamara, G. C., "Adsorption of Some Pesticides on Soils, Clay Minerals and Humic Acid," Diss. Abstr., 29:2260B (1969).

[2] MacNamara, G. C., and S. J. Toth, "Adsorption of Linuron and Malathion by Soils and Clay Minerals," Soil Sci., 109(4):234-240 (1970).

[3] Bowman, B. T., "The Effect of Water Upon Malathion Adsorption Onto Five Montmorillonite Systems," Diss. Abstr. Int., 31(3):1005B-1006B (1970).

[4] Bowman, B. T., R. S. Adams, Jr., and S. W. Fenton, "Effect of Water Upon Malathion Adsorption Onto Five Montmorillonite Systems," J. Agr. Food Chem., 18(4):723-727 (1970).

Meyers et al. (1970)[1] studied the adsorption of malathion on pond sediments and watershed soils. The clay fractions of both the sediment and the soil contained kaolinite, micaceous minerals, and vermiculite. Among several insecticides studied, malathion was adsorbed to the greatest extent.

Konrad et al. (1969)[2] found that the rate of malathion degradation in soils was directly related to the extent of malathion adsorption, suggesting that degradation occurred by a chemical mechanism which was catalyzed by adsorption. In laboratory studies with three different soil types, 50 to 90% of the initial quantity of malathion was degraded in 24 hr, depending on the type of soil, in both sterile and nonsterile systems. No lag phase occurred prior to degradation. In aqueous soil-free systems inoculated with a soil extract, a lag phase of about 7 days occurred, followed by rapid malathion loss. It is concluded that in soils, complete chemical degradation of malathion occurred prior to microbial adaptation to the chemical. The chemical reaction is complete before the end of the biological lag phase is achieved.

Walker and Stojanovic (1973)[3] investigated the chemical and microbiological degradation of malathion in three Mississippi soils (Trinity loam, Freestone sandy loam, and Okolona clay), and in aqueous dilutions prepared from them. In all cases, malathion degradation was more rapid under nonsterile than under sterile conditions, indicating the involvement of soil microorganisms. The amount of microbial as compared to chemical degradation appeared to increase with increased soil organic matter and was directly dependent on soil pH. In all three soils and in the aqueous systems, microbiological degradation predominated. Malathion was quite stable under neutral or acid pH conditions, but was susceptible to hydrolysis in the alkaline range.

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[1] Meyers, N. L., J. L. Arlrichs, and J. L. White, "Adsorption of Insecticides on Pond Sediments and Watershed Soils," Proc. Indiana Acad. Sci., 79:432-437 (1970).

[2] Konrad, J. G., G. Chesters, and D. E. Armstrong, "Soil Degradation of Malathion, a Phosphorodithioate Insecticide," Soil Sci. Soc. Amer. Proc., 33(2):259-262 (1969).

[3] Walker, W. W., and B. J. Stojanovic, "Microbial Versus Chemical Degradation of Malathion in Soil," J. Environ. Qual., 2(2):229-232 (1973).

Getzin and Rosefield (1971) studied the persistence of malathion in nonsterile, heat-sterilized, and radiation-sterilized soils. Malathion (and several other pesticides studied) degraded fastest in nonsterile soils. Malathion decomposed much faster in irradiated than in autoclaved soil.

Chopra and Girdhar (1971)[1/] studied the persistence of malathion in Punjab soils. Malathion was degraded at different rates in the three soils. Degradation increased with increased exposure time to UV light, relative humidity, temperature, and concentration of the insecticide. Malathion decomposed more rapidly in alkaline than in acidic soils.

Nayshteyn et al. (1973)[2/] studied the stability decomposition of malathion and several other pesticides in artificially acidified and alkalinized soils with pH ranges of 3 to 4.6 and 8.7 to 9.6. Malathion was applied at 2 and 200 mg/kg at a soil temperature of 18 to 20°C. Malathion was more stable in the acidic soils. The rate of degradation in native and sterile soils was comparable. The authors concluded that the role of soil microorganisms in the degradation of malathion is of secondary importance compared to that of chemical reactions.

Galley (1972)[3/] used thin-layer chromatography to measure semiquantitatively the persistence of malathion and several other organophosphates in hen house litter. Malathion disappeared within 4 hr of application, while several of the other insecticides studied were considerably more persistent.

Kearney and Helling (1969)[4/] presented an excellent discussion of the pertinent reactions associated with pesticide decomposition in soils. The principal reactions associated with pesticide decomposition in the soil are discussed in considerable detail. However, this review contains few specific data on malathion.

[1/] Chopra, S. L., and K. C. Girdhar, "Persistence of Malathion S-1,2-bis (Ethoxy Carboxyl)Ethyl 0,0-Dimethyl Phosphorodithionate in Punjab Soils," Indian J. Appl. Chem., 34(5):201-207 (1971).

[2/] Nayshteyn, S. Y., V. A. Zhulinskaya, and Y. M. Yurovskaya, "The Stability of Certain Phosphororganic Pesticides in the Soil," Gig. Sanit., 38(7):42-45 (1973).

[3/] Galley, D. J., "Persistence of Some Organo-Phosphorus Insecticides in Hen-House Litter," Pest. Sci., 3(1):19-23 (1972).

[4/] Kearney, P. C., and C. S. Helling, "Reactions of Pesticides in Soils," Residue Rev., 25:25-44 (1969).

Field and Combined Field-Laboratory Studies - Roberts et al. (1962)[1] studied the persistence of malathion (and other insecticides) in soil in Georgia. Malathion was applied at an exaggerated rate of 76.6 lb AI/acre, followed by repeated annual applications of 16 lb AI/acre in the next 2 years. No malathion residues were detected in the soil after the first year, nor after the second and third annual applications.

Laygo and Schulz (1963)[2] reported that malathion applied to soil persisted for 2 days.

Lichtenstein and Schulz (1964)[3] applied malathion at 5 lb AI/acre to Carrington silt loam field plots. Malathion was the least stable of three organophosphate insecticides tested. Only 15% of the applied dose could be recovered 3 days after application. After four additional days, 95% of the quantity applied had disappeared. A residue level of malathion of approximately 0.1 ppm (3.1% of the applied dosage) was reached under field conditions within 8 days.

Monitoring Studies - In the National Soils Monitoring Program for Pesticides, 1,729 samples of cropland soils from 43 states were collected in 1969 (Wiersma et al., 1972[4]). Of these, 66 samples were analyzed for organic phosphate residues, and two of these (3%) contained malathion residues ranging from 0.04 to 0.36 ppm. The mean malathion residue level was 0.01 ppm. One hundred and ninety-nine samples of noncropland soil were also obtained, but none of these were analyzed for organophosphate residues.

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[1] Roberts, J. E., R. D. Chisholm, and L. Koblitsky, "Persistence of Insecticides in Soil and Their Effect on Cotton in Georgia," J. Econ. Entomol., 55(2) (1962).

[2] Laygo, E. R., and J. T. Schulz, "Persistence of Organophosphate Insecticides and Their Effects on Microfauna in Soils," Proc. North Dakota Acad. Sci., 17:64-65 (1963). Quoted from Pimentel (1971).

[3] Lichtenstein, E. P., and K. R. Schulz, "The Effects of Moisture and Microorganisms on the Persistence and Metabolism of Some Organophosphorus Insecticides in Soils, with Special Emphasis on Parathion," J. Econ. Entomol., 57:618-627 (1964).

[4] Wiersma, G. B., W. G. Mitchell, and C. L. Stanford, "Pesticide Residues in Onions and Soil - 1969," Pest. Monit. J., 5(4):345-347 (March 1972).

In the National Soils Monitoring Program for Pesticides in 1970 (Crockett et al., 1970[1/]), soil and crop samples were collected from 1,506 cropland sites in 35 states. Pesticide use records indicated that malathion was used at 84 (6.24%) of the 1,346 sites sampled. No analyses of soil samples for malathion residues are reported. Samples of alfalfa, field corn kernels, cotton stalks and green bolls, grass hay, field corn stalks, cotton seeds, mixed hay, and soybeans (beans) were analyzed for organophosphate residues. Malathion residues were found in four of 18 (22%) samples of cotton stalks and green bolls, ranging from 0.08 to 2.17 ppm, mean 0.16 ppm. Minute residues of malathion (mean less than 0.01 ppm) were also detected in one of 47 (2%) samples of grass hay, and in one of 270 (0.4%) samples of field corn stalks.

In 1969, Wiersma et al. (1972) monitored pesticide residues in commercially grown onions and in the soil on which these onions were grown. A total of 76 sites in 10 major onion-producing states were sampled. According to pesticide use records, malathion had been used on 13.6% of the farms sampled, at an average rate of 2.86 lb AI/acre. No residues of malathion were found in any of the soil or onion samples.

Stevens et al. (1970)[2/] reported on a pilot monitoring study conducted nationwide at 51 locations in 1965, 1966, and 1967 to determine pesticide residue levels in soil. Samples were collected from 17 areas in which pesticides were used regularly, 16 areas with a record of at least one pesticide application, and 18 areas with no history of pesticide use. Pesticide use records indicated that malathion had been used at a number of the sites sampled but only one single detection of a malathion residue is reported, i.e., 0.03 ppm in the soil in one of five fields sampled in Weld County, Colorado. Use records for this field did not show any malathion applications.

[1/] Crockett, A. B., G. B. Wiersma, H. Tai, W. G. Mitchell, and P. J. Sand, "National Soils Monitoring Program for Pesticide Residues - FY 1970," U.S. Environmental Protection Agency, Technical Services Division, unpublished manuscript (1970).

[2/] Stevens, L. J., C. W. Collier, and D. W. Woodham, "Monitoring Pesticides in Soils from Areas of Regular, Limited, and No Pesticide Use," *Pest. Monit. J.*, 4(3):145-164 (December 1970).

The California Department of Water Resources (1969, 1970)[1,2] reported on the pesticide concentrations in surface and subsurface drain effluents in the San Joaquin Valley. In 1969, 14 samples of surface and 41 samples of subsurface drain effluents were analyzed for organophosphate compounds. No malathion residues were detected in any of these samples. In 1970, 18 samples of surface and 60 samples of subsurface drain effluents were analyzed for organophosphates. No malathion residues were detected.

Since the results of the 1972 National Soils Monitoring Program have not yet been published, more recent data was not included in this review.

The scientific data on the residues and fate of malathion in the soil from laboratory, field and monitoring studies reviewed show that malathion is rapidly degraded in the soil. There appears to be some disagreement among investigators on the relative contributions of chemical vs microbiological processes to this degradation. However, all data reviewed indicate that malathion residues in the soil are short-lived. Kearney (1969), in a recent summary of pesticide persistence data, states that malathion normally persists in soil for about 1 week.

Residues in Water

Reviews - Recent general reviews on the fate of organophosphate and other pesticides in water include those by Paris and Lewis (1973)[3] who discussed the chemical and microbial degradation of 10 selected prsticides in aquatic systems; and by Faust and Suffet (1966)[4] on the recovery, separation, and identification of organic pesticides from

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[1] California Department of Water Resources, "San Joaquin Valley Drainage Monitoring Program, 1969 Summary," Sacramento, California (1969). In: Li and Fleck (1972).

[2] California Department of Water Resources, "San Joaquin Valley Drainage Monitoring Program, 1970 Summary," Sacramento, California (1970). In: Li and Fleck (1972).

[3] Paris, D. F., and D. L. Lewis, "Chemical and Microbial Degradation of Ten Selected Pesticides in Aquatic Systems," Residue Rev., 45:95-124 (1973).

[4] Faust, S. D., and I. H. Suffet, "Recovery, Separation, and Identification of Organic Pesticides from Natural and Potable Waters," Residue Rev., 15:44-114 (1966).

natural and potable waters. Furthermore, Chesters and Konrad (1971)[1] summarized the state of the art concerning the effects of pesticide usage on water quality in a brief review article, drawing on a considerable number of literature references. All of these are good summaries of the state of the art in the fields indicated, but contain relatively little specific detail on malathion.

Laboratory and Field Studies - Eichelberger and Lichtenberg (1971)[2] investigated the persistence of malathion and a number of other common pesticides in raw river water over an 8-week period. Aliquots of 10 µg/liter of malathion from a freshly prepared 0.1% solution in acetone were injected into samples of raw water from the Little Miami River, a relatively small stream receiving domestic and industrial wastes and farm runoff. The dosed raw river water was kept in the laboratory in closed glass containers at room temperature, exposed to natural and artificial light. Under these conditions, 25% of the original concentration of malathion remained after 1 week, 10% after 2 weeks, zero after 4 weeks. The same concentration of malathion was added to distilled water in the same manner in another test. Malathion remained stable in distilled water for 3 weeks. The authors believe that this indicates probable occurrence of a biological reaction in the raw river water, but point out that this was not proved conclusively.

At a recent scientific meeting, Wolfe et al. (1974)[3] reported that malathion can form relatively persistent and possibly toxic degradation products in water. Laboratory tests showed that malathion breaks down in water by two competing pathways, one yielding compounds that are considered nontoxic to aquatic organisms. The second pathway, which is favored in colder water (35°F), results in the formation of malathion acids which may possess some of the toxic properties of malathion and appeared to be more persistent in the environment than the parent compound. The acid hydrolysis of malathion is five orders of magnitude slower; even at pH 5, acid hydrolysis is too slow to compete with basic hydrolysis. Photochemical studies indicate that degradation of malathion by direct sunlight photolysis would occur at a rate too slow to be environmentally significant. At pH 8 and 28°C, malathion had a half-life in water of about 1 month. The lifetime of malathion in water can vary from several days to several months, depending upon temperatures and other environmental conditions.

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[1] Chesters, G., and J. G. Konrad, "Effects of Pesticide Usage on Water Quality," Bioscience, 21(12):565-569 (1971).

[2] Eichelberger, J. W., and J. J. Lichtenberg, "Persistence of Pesticides in River Water," Environ. Sci. Technol., 5(6):541-544 (1971).

[3] Wolfe, N. L., R. G. Zepp, G. L. Baughman, and J. A. Gordon, "Kinetic Investigation of Malathion Degradation in Water," paper presented at the 167th National Meeting of the American Chemical Society, Division of Pesticide Chemistry, Los Angeles, California (1974).

Konrad et al. (1969) studied the effect of pH on malathion degradation in aqueous systems. In 7 days, malathion degraded 100% at pH 11, 25% at pH 9, 0% at pH 6, 4, and 2.

Lewis and Eddy (1959)[1] applied malathion (from an emulsifiable formulation) at 1, 3, and 6 lb AI/surface acre to log ponds for the control of mosquito larvae in the vicinity of Corvallis, Oregon. Under these conditions, malathion provided protection against mosquito reinfestation for 2.5 to 6 weeks.

Guerrant et al. (1970)[2] measured environmental residues of malathion after an aerial ULV application. Malathion low-volume concentrate (95%) was applied at the rate of 3.0 fl oz/acre. The amount of malathion deposited on the surface in the treated area was determined by measuring the amount found on exposed filter papers; the average concentration found was 1.5 mg/sq ft, or 65% of the applied dosage. The maximum concentration found in environmental waters was 0.5 ppm malathion. This concentration degraded with a half-life ranging from 0.5 to 10 days, depending primarily upon water pH.

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[1] Lewis, L. F., and G. W. Eddy, "Control of Mosquito Larvae in Log Ponds in Oregon," J. Econ. Entomol., 52:259-260 (1959).

[2] Guerrant, G. O., L. E. Fetzer, Jr., and J. W. Miles, "Pesticide Residues in Hale County, Texas, Before and After Ultra-Low Volume Aerial Application of Malathion," Pest. Monit. J., 4(1):14-20 (1970).

Lenon et al. (1972)[1] measured insecticide residues in water and sediments from cisterns on the U.S. and British Virgin Islands in 1970. Malathion is used extensively on these islands for insect control purposes. Malathion residues were found in only two of 49 water samples analyzed, at very low concentrations (0.14 and 0.01 ppb, respectively). However, evidence of an unknown malathion metabolite was found in all 49 water samples. This metabolite was not chemically identified; therefore, the importance of its presence could not be interpreted. Its detection is reported to suggest the previous presence of its precursor, malathion, in all samples, consistent with its extensive use in the area.

Rueckert and Ghelberg (1971)[2] reported that malathion emulsions stimulated oxygen consumption by 50 to 60% when added to slightly polluted river water at 3 to 4 mg/liter, while oxygen production was scarcely affected. At high concentrations, malathion innibited oxygen production completely. When the insecticide-dosed water samples were stored, the inhibitory effects decreased. These studies were conducted at the Sanitary Health Research Institute at Cluj, Rumania. In a report from the same Institute, Nagy et al. (1971)[3] described laboratory investigations on the persistence of malathion (and several other pesticides) in water. Malathion was added to water at pH 5 to 5.5 in concentrations of 0.2 to 150 mg/liter. Malathion was the least persistent among the chemicals studied (7 to 21 days). Conversely, when odor thresholds were studied, malathion was most persistent (21 days), while the odors of other organophosphate insecticides persisted for only 5 to 10 days.

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[1] Lenon, H., L. Curry, A. Miller, and D. Patulski, "Insecticide Residues in Water and Sediment from Cisterns on the U.S. and British Virgin Islands," Pest. Monit. J., 6(3):188-193 (December 1972).

[2] Rueckert, I., and N. Ghelberg, "Experimental Investigation into the Influence of Some Organic-Phosphorus Insecticides on the Oxygen Content of Water," Deut. Gewaesserk. Mitt., 15(1):16-23 (1971).

[3] Nagy, S., R. Tomus, and N. Chelberg, "Laboratory Investigations into the Persistence in Water of Some Pesticides of Phosphate Ester Nature," Egeszsegtudomany, 15:65-73 (1971).

Jirik et al. (1971)[1] studied the degradation of malathion in surface water. When malathion was added to environmental water containing a natural microbial population at a concentration of 10 ppm, it degraded almost completely within 10 days. The microflora present in the water participated in the decomposition of malathion, and there was no evidence of any change in the microflora due to the presence of malathion.

Greve (1972)[2] reported that residues of malathion were identified in water of the Rhine River in Germany at 0.01 to 0.1 ppb.

The data reviewed in this subsection indicate that malathion residues in water are degraded rather rapidly. In practically all experiments reviewed, residues of malathion in water degraded more rapidly than those of other pesticides studied under the same experimental conditions. The very recent findings by Wolfe et al. (1974) concerning the formation of more stable metabolites from the degradation of malathion in water emphasizes the desirability of obtaining more information on the chemical nature and the biological properties of the degradation products of malathion (as well as of many other pesticides).

Monitoring Data - A number of agencies are listed in the Federal Environmental Monitoring Directory (Council on Environmental Quality, 1973[3]) with the indication that they conduct monitoring studies on pesticides in water and/or aquatic organisms. All of these agencies were contacted, but none of them were able to supply data on malathion residues in water or aquatic organisms.

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[1] Jirik, V., J. Pokorny, and H. Culikova, "Investigation of the Degradation of the Organophosphate Insecticide Fosfotion in Surface Water," Cesk. Hyg., 16(6):177-182 (1971).

[2] Greve, P. A., "Toxic Organic Trace Pollutants in Surface Water," Chem. Weekbl., 41(68):11,13,15 (1972).

[3] Council on Environmental Quality, The Federal Environmental Monitoring Directory, U.S. Government Printing Office, Washington, D.C. (1973).

Residues in Air

Harris and Lichtenstein (1961)[1] exposed caged vinegar flies (Drosophila melanogaster) and houseflies (Musca domestica) to vapors from quartz sand treated with malathion at the rate of 4 ppm. There was no mortality among insects of either species that were kept in screened cages above the malathion-treated sand for periods of 6 or 24 hr. Under the same conditions, 100% mortality of the test insects was obtained with several other insecticides, demonstrating the validity of the method.

Hopkins (1967)[2] studied the effects of humidity on the persistence of malathion residues on leaf surfaces. The upper surfaces of the two primary leaves of 2- to 3-week old bean plants were treated with malathion at the rate of 400 μg/leaf. During the first 5 hr after treatment, relative humidity over a range of 45 to 85% had no significant effect on the rate of disappearance of malathion deposits from the leaf surfaces. The authors concluded that volatilization by moving air currents and absorption by the leaf cuticle were not significantly affected by the relative humidity of the air during the initial period when the superficial layers of the malathion deposit were more susceptible to loss. As the residue diminished and became stabilized on the plant surface after the first half-life, humidity began to exert a detectable effect.

Alessandrini and Amormino (1954)[3] determined the volatility of malathion and several other insecticides. Two milliliters of a 1% solution of malathion in ethyl ether were placed on a 4-in. watch glass. The ether was allowed to evaporate, and the residues were maintained at a constant temperature of 35°C for a period of 90 days. Under these conditions, malathion was the least volatile among the organophosphate insecticides studied. Its weight loss after 15 days ranged from 0 to 7.5% and 41 to 49% after 90 days. Three different grades of malathion, i.e., pure grade 99.5%, technical grade 95%, and technical grade 86 to 90%, were included in these tests. The purest malathion sample exhibited the lowest volatility.

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[1] Harris, C. R., and E. P. Lichtenstein, "Factors Affecting the Volatilization of Insecticidal Residues from Soils," J. Econ. Entomol., 54(5):1038-1045 (1961).

[2] Hopkins, T. L., "Humidity Effects on the Persistence of Malathion Leaf-Surface Residues," J. Econ. Entomol., 60(4):1167-1168 (August 1967).

[3] Alessandrini, M. E., and V. Amormino, "Comparative Determinations of the Volatility of Some Organic Phosphorus Insecticides," International Symposium on Control of Insect Vectors of Disease, pp. 93-96 (1954).

Stanley et al. (1971)[1] conducted a pilot study to establish a system for measuring the extent of atmospheric contamination of the air by pesticides in nine localities throughout the United States. Samples were analyzed for 19 pesticides and metabolites, including malathion. Malathion was found in only one of the nine sampling locations, i.e., Orlando, Florida. At that location, four samples of 99 analyzed contained detectable amounts of malathion. The maximum level found was 2.0 ng/m^3 of air.

Truhaut (1971)[2] discussed the problems surrounding the establishment of maximum allowable concentrations of toxic substances in air in the occupational environment, and the application of this concept to community air pollution. Complexities involved include different analytical techniques, the instability of certain compounds, as well as divergent interpretations of the same basic data in different countries. As an example, the author mentions that industrial hygiene authorities in the United States have established a maximum allowable concentration of malathion in air at 15 mg/m^3, whereas in the USSR, this value is 0.5 mg of malathion per cubic meter.

No further reports were found on the origin, presence, persistence, and significance of malathion residues in air.

Residues in Nontarget Plants

No reports were found on the metabolism, or on residues of malathion in or on nontarget higher plants.

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[1] Stanley, C. W., J. E. Barney II, M. R. Helton, and A. R. Yobs, "Measurement of Atmospheric Levels of Pesticides," Environ. Sci. Technol., 5(5):430-435 (1971).

[2] Truhaut, R., "The Problem of Maximum Allowable Concentrations of Air Pollutants," Prod. Probl. Pharm., 25(8):530-548 (1971).

Bioaccumulation, Biomagnification

No information dealing directly with the possible bioaccumulation or biomagnification of malathion was obtained. However, the physical, chemical, and biological properties of malathion make it most unlikely that biomagnification in food chains or food webs occurs, and there is no evidence that it does.

Metcalf (1972)[1] states: "Both the organophosphates and carbamates are not persistent in soil and do not accumulate in body fat."

Environmental Transport Mechanisms

The data reviewed in the preceding subsections of this report section indicate that under field conditions, malathion is rapidly degraded by chemical as well as by biological mechanisms. A majority of the experimental data indicate that chemical degradation is most important under field conditions. Several reports indicate that volatilization does not appear to be a major transport mechanism by which malathion may move away from target sites after application.

The propensity of malathion was determined for volatilization and leaching under simulated field conditions for loam soils at 25°C at an annual rainfall of 59 in. (150 cm) (von Rumker and Horay, 1972[2]). Volatilization of pesticides under these conditions, i.e., from a porous, sorptive medium (loam soil) in a nonequilibrium situation, is different from volatilization from an inert surface or from the chemical's own surface. Therefore, the environmental volatilization index assigned to pesticides studies in this manner may or may not parallel a chemical's vapor pressure. By this method, malathion rated a volatilization index of 2, indicating an estimated median vapor loss from treated areas of 1.8 lb/acre/year. This index number indicates that the propensity for volatilization of malathion from treated fields is in the intermediate range, compared to many other pesticides.

Leaching index numbers for pesticides indicate the approximate distance that the chemical would move through the standardized loam soil profile under an annual rainfall of 59 in. (150 cm). Under these conditions, malathion rated a leaching index number of 2 to 3, indicating movement of 6 to 10 in.

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[1] Metcalf, R. L., "DDT Substitutes," Crit. Rev. Environ. Contr., 3(1): 25-59, Ref. 110 (1972).

[2] von Rümker, R., and F. Horay, Pesticide Manual, Vol. I, Department State, Agency for International Development (1972).

It appears that under field conditions, malathion residues are unlikely to migrate through ecosystems by environmental transport mechanisms to any significant extent. Malathion, after more than 20 years of use for a variety of pest control purposes, has produced no apparent adverse effects on the environment or man.

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SUBPART II. D. PRODUCTION AND USE

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This section contains data on the registered uses, and on the production, domestic supply, and use patterns of malathion. The section summarizes rather than interprets scientific data reviewed.

Registered Uses of Malathion

Federally Registered Uses - Malathion has a very broad spectrum of effectiveness against insects and mites. It is registered and recommended in the United States for use on about 130 different crops, on livestock and pets, and on agricultural premises such as barns (including dairy barns and milk rooms), feedlots, holding pens, poultry houses, feed rooms, and grain bins. The foregoing count of 130 crops includes several dozen minor vegetables counted as only one crop. Tolerances for malathion residues have been established on at least 127 raw agricultural commodities.

The registered uses of malathion by crops, established tolerances, dosage rates, and use limitations are summarized in the EPA Compendium of Registered Pesticides.[1/].

The registered uses of malathion are detailed in this subsection in a set of three tables as follows:

Table 26: Insect and mite pests against which malathion is recommended, in alphabetical order by common names, including scientific names.

This table includes 97 entries. In order to keep it to a manageable length, many individual species of target insects have been grouped together by genera, families, or even orders (examples: "aphids," "mites," "leafminers," etc.).

Table 27: Registered uses of three commonly used formulations of malathion. The formulations used are: 57% emulsifiable liquid (5 lb AI/gal); 25% wettable powder; and 4% dust. Table 27, taken from the manual of label claims for malathion prepared by the American Cyanamid Company (the only basic producer of malathion in the United States) and summarizes the registered uses of the above three malathion formulations by crops; insects and other pests controlled on each crop; recommended dosage rates; residue tolerances; and general and specific directions for, and limitations of use.

[1/] U.S. Environmental Protection Agency, EPA Compendium of Registered Pesticides: Insecticides, Araricides, Molluscides and Anti-Fouling Compounds, Vol. III (1973).

Table 25. INSECT AND MITE PESTS AGAINST WHICH MALATHION IS RECOMMENDED (in alphabetical order by common names)

Alafalfa caterpillar	Colias eurytheme
Alafalfa looper	Autographa californica
Alfalfa weevil	Hypera postica
Ants	Family Formicidae
*Aphids	Family Aphididae
Armyworm	Pseudaletia unipuncta
Asparagus beetle	Crioceris asparagi
Bagworm	Thyridopteryx ephemeraeformis
Bed bug	Cimex lectularis
Beet leafhopper	Cruculifer tenellus
Birch leafminer	Fenusa pusilla
Blackheaded fireworm	Rhopobota naevana
Blueberry fruit fly	Rhagoletis mendax
Body lice	Pediculus humanus humanus
Boxwood leafminer	Monarthropalpus buxi
Brown cotton leafworm	Acontia dacia
Brown dog tick	Rhipicephalus sanguineus
Cabbage looper	Trichoplusia ni
Carpet beetle	Anthrenus scrophulariae
Cat flea	Ctenocephalides felis
Caterpillars	Order Lepidoptera
Celery looper	Anagrapha falcifera
Centipedes	Class Chilopoda
Cereal leaf beetle	Oulema melanopus
Cherry fruit fly	Rhagoletis cingulata
Cherry fruitworm	Grapholitha packardi
Chigger	Family Trombiculidae
Cigarette beetle	Lasioderma serricorne
Cloths moths	Family Tineidae
Clover leaf weevil	Hypera punctata
Cockroaches	Order Dictyoptera
Codling moth	Lasperresia pomonella
Confused flour beetle	Tribolium confusum
Corn earworm	Heliothis zea
Corn rootworm	Diabrotica spp.
Cotton leafperforator	Bucculatrix thurberiella
Cotton leafworm	Alabama argillacea
Cranberry fruitworm	Acrobasis vaccinii
Cucumber beetle	Family Chrysomelidae
Diamondback moth	Plutella xylostella
Darkwinged fungus gnat	Family Sciaridae
Dog flea	Ctenocephalides canis
Driedfruit beetle	Carpophilus hemipterus

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* Refer to manufacturer labels for specific pest recommendations.

Source: American Cyanamid Co., CYTHION - Manual of Label Claims for Insect Control.

Table 25. (Continued)

Drosophila	Family Drosophilidae
Earwigs	Family Dermaptera
European pine sawfly	*Neodiprion sertifer*
European pine shoot moth	*Rhyacionia buoliana*
Eyespotted budmoth	*Spilonota ocellana*
Fall armyworm	*Spodoptera frugiperda*
False chinch bug	*Nusius ericae*
Flat grain beetle	*Cryptolestes pusillus*
Flea beetles	Family Chrysomelidae
Fourlined plant bug	*Poecilocapsus lineatus*
Fruit flies	Family Tephritidae
Truittree leafroller	*Archipes argyrospilus*
Garden webworm	*Loxostege rantalis*
Granary weevil	*Sitophilus granarius*
Grape phylloxera	*Phylloxera vitifoliae*
Grasshoppers	Family Acrididae
Greenbugs	Aphididae
Green cloverworm	*Plathypena scabra*
Greenhouse thrip	*Heliothrips haemorrhoidalis*
Green stink bug	*Acrosternum hilare*
Ground pearl	Family Margarodidae
Harlequin bug	*Margantia histrionica*
Head lice	*Pediculus humanus capitis*
Hemlock looper	*Lambdina fiscellaria*
Horn fly	*Haematobia irritans*
Indian meal moth	*Plodia interpunctella*
Imported cabbageworm	*Pieris rapae*
Imported currentworm	*Nematus ribesii*
Japenese beetle	*Popillia japonica*
Khapra beetle	*Trogoderma granarium*
Lace bugs	Family Tingidae
Larch casebearer	*Coleophora laricella*
Leafhoppers	Family Cicadellidae
Lesser grain borer	*Rhyzopertha dominica*
Lesser peach tree borer	*Synanthedon pictipes*
Lice	Orders Anoplura/Mallophaga
Lygus bugs	*Lygus* spp.
Mealybugs	Family Pseudococcidae
Mediterranean fruit fly	*Ceratitis capitata*
Mexican bean beetle	*Epilachna varivestis*
Milipedes	Class Diplopoda
*Mites	Order Acarina
Morningglory leafminer	*Bedellia somnulentella*
Mosquitoes	Family Culicidae
Nitidulid beetles	Family Nitidulidae
Northern fowlmite	*Ornithonyssus sylvarum*
Oak kerms	*Kermes pubescens*
Omniverous leaftier	*Cnephasis longana*
Omniverous looper	*Sabulodes caberata*
Onion maggot	*Hylemya antiqua*
Orange tortrix	*Argyrotaenia citrana*

Table 25. (Continued)

Oriental fruit moth	*Grapholitha molesta*
Otodectic mange mites	*Otodectes* spp.
Peach twig borer	*Anarsia lineatella*
Pea weevil	*Bruchus pisorum*
Pear psylla	*Psylla pyricola*
Pecan bud moth	*Gretchena bolliana*
Pecan leaf casebearer	*Acrobasis juglandis*
Pecan nut casebearer	*Acrobasis nuxvorella*
Pecan phylloxera	*Phylloxera devastatrix*
Pepper maggot	*Zonosemata electa*
Phorid flies	Family Phoridae
Pickleworm	*Diaphania nitidalis*
Plum curculio	*Conotrachelus nenuphar*
Potatoe leafhopper	*Empoasca fabae*
Redbanded leafroller	*Argyrotaenia velutinana*
Red flour beetle	*Tribolium castaneum*
Rice leafminer	*Hydrellia griseola*
Rice stinkbug	*Oebalus pugnax*
Rice weevil	*Lissorhoptrus oryzophilus*
Rose leafhopper	*Edwardsiana rosae*
Rusty grain beetle	*Cryptolestes ferrugineus*
Sap beetle	Family Nitidulidae
Saratoga spittlebug	*Aphrophora saratogensis*
Sarcoptic mange	Family Sarcoptidae
Sawtoothed grain beetle	*Oryzaephilus surinamensis*
*Scales	Superfamily Coccoidea
Scorpions	Order Scorpionida
Shaft lice	*Menopon gallinae*
Sharpnosed leafhopper	*Scaphytopius magdalensis*
Sheep ked	*Melophagus ovinus*
Silverfish	*Lepisma saccharina*
*Soft scales	Family Coccidae
Sorghum midge	*Contarinia sorghicola*
Spiders	Order Araneida
Spittlebugs	Family Cercopidae
Spruce budworm	*Choristoneura fumiferana*
Squash vine borer	*Mellittia cucurbitae*
Strawberry leafroller	*Ancylis comptana*
Strawberry root weevil	*Otiorhynchus ovatus*
Sugarbeet root maggot	*Tetanops myopaeformis*
Tarnished plant bug	*Lygus lineolaris*
Tent caterpillar	*Malacosoma* spp.
Thrips	Order Thysanoptera
Ticks	Order Acarina
Unspotted tentiform caterpillar	*Parornix geminatella*
Vetch bruchid	*Bruchus brachialis*
Walnut husk fly	*Rhagoletis completa*
Western yellowstriped armyworm	*Spodoptera praefica*
Whiteflies	Family Aleyrodidae
Yellownecked caterpillar	*Datana ministra*

Table 26. REGISTERED USES, DOSAGE RATES, TOLERANCES, AND USE LIMITATIONS FOR COMMONLY USED MALATHION FORMULATIONS
(57% emulsifiable concentrate, 25% wettable powder, and 4% dust)

CYTHION®
INSECTICIDE
THE PREMIUM GRADE MALATHION

MANUAL
of
LABEL CLAIMS
for
INSECT CONTROL

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CYANAMID

AMERICAN CYANAMID COMPANY • AGRICULTURAL DIVISION • P.O. BOX 400, PRINCETON, N. J. 08540

INSECT CONTROL WITH CYTHION® INSECTICIDE

THE PREMIUM GRADE MALATHION

A development of American Cyanamid Company, CYTHION® is the first insecticide to offer control of so many insects, and at the same time to have such a low hazard to man and animal. CYTHION controls a great diversity of insects including aphids, spider mites, scales and house flies as well as a wide range of other sucking and chewing insects attacking fruits, vegetables, ornamentals and animals — a total of over one hundred insects on more than ninety crops.

FORMULATIONS: American Cyanamid Company produces and sells CYTHION The Premium Grade Malathion* which many well known manufacturers use to formulate emulsifiable liquids, wettable powders, dusts, and pressurized sprays under their own brand names.

COMPATIBILITY: CYTHION is compatible in spray tank mixes with most insecticides and fungicides: DDT, lead arsenate, methoxychlor, mineral oil, TDE, CYPREX® Fruit Fungicide, ferbam, glyodin, captan, tribasic copper sulfate, sulfur, zineb, maneb, ziram, KARATHANE, dieldrin, aldrin, chlordane, toxaphene, parathion, and other organic phosphates. There are no phytotoxic effects or decrease in effectiveness when CYTHION is used in these tank mix combinations. Spray tank mixtures of CYTHION with alkaline insecticides and fungicides should be applied promptly.

For proper mixing, the spray tank should be at least 3/4 filled with water before CYTHION formulation is added. Mechanical agitation or recirculation through the pump by-pass to the tank is usually sufficient for maintaining a good dispersion.

Because uniform dispersibility and sprayability may be influenced by the pesticide combinations used, it is recommended that compatibility be determined before adding pesticides to the spray tank.

*O,O-dimethyl phosphorodithioate of diethyl mercaptosuccinate
®Registered Trademark of American Cyanamid Company

Table 26. (Continued)

FIELD CROPS

MIXING SMALL QUANTITIES: For mixing small quantities, use 1 teaspoonful of emulsifiable liquid per gallon for each pint used per 100 gallons. Use 1 tablespoonful of 25% wettable powder per gallon for each pound used per 100 gallons.

CYTHION USES: Uses for CYTHION that have been registered by the Pesticides Regulation Division, U.S. Department of Agriculture, are shown in the charts that follow.

When it is necessary to observe special precautions, these are indicated under the registered use.

NOTE: CYTHION may cause spotting on automobile paint finishes. Cars should not be sprayed directly. If accidental exposure does occur, the car should be washed immediately.

APPLICATION: Rates of application or concentration included in the following tables are shown as 57% emulsifiable liquid, 25% wettable powder, or 4% dust. For ground applications on the crops listed, unless otherwise noted, the specified amounts of the emulsifiable liquid or wettable powder should be applied in sufficient water for good coverage, usually 25 to 50 gallons of water per acre. Applications by aircraft should be made in 2 to 10 gallons of water per acre. Do not make applications when winds exceed 5 miles per hour.

Repeat applications should be made as needed unless otherwise indicated.

Consult your State Experiment Station or State Agricultural Extension Service for additional information as the number, rates, and timing of application needed will vary with local conditions.

RESIDUES: Residue tolerances for CYTHION established by the Food and Drug Administration are shown in the following tables. These tolerances are established in accordance with the pre harvest intervals which are also listed.

Those uses for which "NR" is indicated were previously "no residue" registrations. Tolerances and intervals for these uses are subject to pending petitions.

		AMOUNT PER ACRE				
CROP	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
COTTON	Boll weevil	1-2 qts.	—	25-50 lbs	2 ppm on cotton seed	0
		For control of worms and weevils, CYTHION should be used in combination with other recommended insecticides				
	Desert spider mite Cotton aphid Leafhoppers White flies Cotton leafworm Brown cotton leafworm Cotton leaf perforator Thrips Lygus bugs	1-2 qts.	—	10-25 lbs	2 ppm on cotton seed	0
	Fleahoppers	1-1½ pts	—	10-25 lbs	2 ppm on cotton seed	0
	Fall armyworms Grasshoppers Garden webworms	1½-3 pts	—	25-50 lbs	2 ppm on cotton seed	0
HOPS	Aphids Mites	—	2 lbs.	—	NR	10
MINT	Aphids Spider mites Leafhoppers	1½ pts.	—	—	8 ppm	7
	Adult flea beetles Caterpillars	1½ pts.	—	25 lbs	8 ppm	7

Table [illegible] (Continued)

FIELD CROPS

CROP	PEST	AMOUNT PER ACRE 57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
PEANUTS	Thrips	1½ pts	4 lbs	—	NR	30
	Potato leafhopper	—	—	20-25 lbs	NR	30
RICE (Grain form)	Rice leaf miner	2½ pts	—	—	8 ppm	7
		Make first application shortly after the first blades appear on the surface of the water				
	Rice stink bug	1-1½ pts	—	—	8 ppm	7
		Apply during the early milk and dough stage of growing rice				
SAFFLOWER	Aphids Lygus bug Grasshoppers*	1½-2 pts	—	—	NR	3
		*Several repeat applications may be needed for controlling grasshoppers				
SOYBEANS	Mexican bean beetle	2½-3 pts	6-8 lbs	40-50 lbs	NR	3
SUGAR BEETS	Aphids Spider mites	1½-2 pts	5 lbs	30 lbs	8 ppm	7*
		*If tops are to be used as feed or grazed				
	Grasshoppers	3 pts	8 lbs	—	8 ppm	7*
		*No application if tops are to be used as feed				
TOBACCO	Aphids	1½-2½ pts	—	25-30 lbs	NR	7
		Use maximum dosage in plant bed				
VETCH	Pea Aphid Vetch bruchid	1½-2 pts	—	30 lbs	NR	7
	Omniverous leaf tier	1½-2 pts	—	—	NR	7

FORAGE CROPS

CROP	PEST	AMOUNT PER ACRE 57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
ALFALFA	Aphids Potato leafhopper Spider mites Alfalfa weevil larvae Spittlebug	1½-2 pts	—	30 lbs	135 ppm	0
		For control of alfalfa weevil larvae under conditions of low temperatures and for control of heavy infestations of spittlebug, a CYTHION + methoxychlor combination may be preferred. Consult your local State Experiment Station.				
	Vetch bruchid	—	—	30 lbs	135 ppm	0
	Grasshoppers	1½-2 pts	—	—	135 ppm	0
	Spotted alfalfa aphid	1½-2 pts	—	12-20 lbs	135 ppm	0
		Use higher dosage on taller alfalfa				
	Clover leaf weevil	1½ pts	—	—	135 ppm	0
		Apply in spring when alfalfa is 2-6 inches tall				
	Pea aphid	1 pt	—	—	135 ppm	0
	Lygus bug	1½-2 pts	—	—	135 ppm	0
	Armyworms	2 pts	3 lbs	35 lbs	135 ppm	0
		Make full coverage application when larvae are small				
		Apply to alfalfa in bloom only in the evening or early morning when bees are not working in the field or are not hanging on outside of hives				
CLOVER	Aphids Mites	1½-2 pts	4 lbs	25-30 lbs	135 ppm	0
	Grasshoppers Leafhoppers	1½-2 pts	4 lbs	—	135 ppm	0
	Clover leaf weevil	1½ pts	—	—	135 ppm	0
		Apply in spring when clover is 2-6 inches tall				
		Do not apply to clover in bloom				
GRASS CROPS						
Grass & Grass hay (cont. next pg.)	Grasshoppers	1½-2 pts OR 1½ pts in 1 gal. diesel fuel oil*	—	—	135 ppm	0
		Repeat applications may be needed after hatching and before movement to crops takes place				
	Aphids Leafhoppers	1½-2 pts OR 1½ pts in 1 gal. diesel fuel oil*	2 lbs	30-40 lbs	135 ppm	0
		*Apply by aircraft or turbine blower sprayer				

Table 26. (continued)

FORAGE CROPS

		AMOUNT PER ACRE				
CROP	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
GRASS CROPS **Grass & Grass hay**	Armyworms	2 pts OR 1½ pts in 1 gal diesel fuel oil*	3 lbs	35-40 lbs	135 ppm	0
			Apply when larvae are small			
		*Apply by aircraft or turbine blower sprayer				
Pasture & Range grass	Grasshoppers	1½-2 pts OR 1½ pts in 1 gal diesel fuel oil*	—	—	135 ppm	0
		Repeat applications may be needed after hatching and before movement to crops takes place				
	Aphids Leafhoppers	1½-2 pts OR 1½ pts in 1 gal diesel fuel oil*	2 lbs	30-40 lbs	135 ppm	0
		*Apply by aircraft or turbine blower sprayer				
Barn grass Canary grass Fescue Orchard grass Red top Timothy Yellow foxtail	Cereal leaf beetle	1-1½ pts	1-4 lbs	—	135 ppm	0
GRAIN CROPS Barley Corn Oats Wheat	Cereal leaf beetle	1-1½ pts	1-4 lbs	—	8 ppm	7 5-corn
Barley Oats Rye Wheat	English grain aphid Greenbugs Grasshoppers*	1½ pts	—	—	8 ppm	7
		*Make full coverage to hatching areas when nymphs are young				
	Armyworms	2 pts	—	—	8 ppm	7
NON-AGRICULTURAL LANDS (wastelands, roadsides, soil bank lands not to be grazed)	Grasshoppers	1½-3 pts OR 1½-3 pts in 1 gal diesel fuel oil*	—	—	—	5
		*Apply by aircraft or turbine blower sprayer Repeat applications may be needed after hatching and before movements to crops take place				

VEGETABLES

		AMOUNT PER ACRE				
CROP	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
ARTICHOKES	Aphids	1-2 pts	—	—	NR	10
	Leafhoppers	1½ pts	—	—	NR	10
ASPARAGUS	Asparagus beetle	2 pts	—	—	8 ppm	1
	Thrips	1½-2 pts	—	25-30 lbs	8 ppm	1
BEANS (Lima, green, snap, navy, red kidney, wax, cowpeas, black-eyed peas)	Mexican bean beetle	1½ pts	—	30-35 lbs	8 ppm	1
	Leafhoppers	—	—	30-35 lbs	8 ppm	1
	Spider mites	1-1½ pts	—	—	8 ppm	1
	Japanese beetle	1½-2 pts	5 lbs	35 lbs	8 ppm	1
		Make 2 or more applications as needed				
	Aphids Cucumber beetle	2 pts	5 lbs	30 lbs	8 ppm	1
DRY BEANS (California & Northwestern U.S.)	Lygus bugs	1½-2 pts	—	—	8 ppm	1
LENTILS	Cowpea aphids Pea aphids	1½ pts	—		NR	—
COLE CROPS AND LEAFY VEGETABLES Broccoli, Brussels sprouts, Cabbage, Collards, Dandelions, Kale, Kohlrabi, Mustard greens, Parsley, Swiss chard, Turnips, Watercress	Aphids	1½-2 pts	2 lbs	30 lbs	8 ppm	7 3-Turnips and Broccoli 21-Parsley
	Flea beetles (on mustard greens only)	1½-2 pts	4-5 lbs	25-30 lbs	8 ppm	7
	Caterpillars (on cauliflower, collards, Brussels sprouts and broccoli only)	2 pts	5 lbs	30 lbs	8 ppm	7 3-Broccoli
	Harlequin cabbage bug (on collards only)	1 pt	—	—	8 ppm	7
	Imported cabbage worm, cabbage looper, and diamondback moth	NOTE For control of cabbage loopers, worms, and diamondback moths, CYTHION should be used in combination with other recommended insecticides				

Table 26. (Continued)

VEGETABLES

VEGETABLES

CROP	PEST	AMOUNT PER ACRE 57% Emulsifiable Liquid	 25% Wettable Powder	 4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
Cauliflower	Aphids	—	—	50 lbs.	8 ppm	7
	Caterpillars	2 pts	5 lbs	30 lbs	8 ppm	7
Celery (Anise* and fresh leaves and stalks only)	Aphids Spider mites	1½ pts	—	—	8 ppm	7
		*Do not use on crops grown for seed and oil				
Endive (escarole)	Aphids Mites	1½-2 pts	2 lbs	30-40 lbs	8 ppm	7
Lettuce	Leafhoppers Aphids	2 pts	5 lbs	30 lbs	8 ppm	Leaf 14
	Mites	—	—	30-40 lbs	8 ppm	Head 7
	Cabbage looper	3 pts	—	30-40 lbs	8 ppm	
		NOTE For control of cabbage loopers, worms, and diamondback moths, CYTHION should be used in combination with other recommended insecticides				
Spinach	Aphids	2 pts	—	30-35 lbs	8 ppm	7
CORN* (Field, Sweet and Pop)	Corn earworm	—	—	40 lbs	See note	5
		Make 4-5 applications at 3-5 day intervals Begin treatment when 10% of ears show silk				
	Aphids Sap beetle Thrips	1½ pts	—	40 lbs	See note	5
	Grasshoppers	1½ pts	—	—	See note	5
		Make full coverage applications to hatching areas when nymphs are young				
	Corn rootworm adults (for protection of silks)	1½ pts	—	—	See note	5
		Make full coverage applications to foliage when adult beetles become abundant				
		NOTE 2 ppm on ear with husk removed and 8 ppm on forage				
	* INJURY MAY OCCUR IN THE WHORL OR SILK STAGE WITH EMULSIFIABLE LIQUID AND IN THE WHORL STAGE WITH DUST					
CUCURBITS						
Cucumbers	Aphids Spider mites	1½ pts	—	30-35 lbs	8 ppm	1
	Pickleworm	1½ pts.	6 lbs.	30-35 lbs.	8 ppm	1
	Cucumber beetles	3 pts	7 lbs.	45 lbs.	8 ppm	1
		Do not apply unless plants are dry.				
Melons (Cantaloupes, Casabas, Crenshaws, Honeydews, Honey balls, Muskmelons, Persians, Watermelons and Hybrids of these)	Leafhoppers	—	—	30-35 lbs.	8 ppm	1
	Pickleworm	—	—	20-40 lbs	8 ppm	1
	Aphids Spider mites	1½ pts	—	30-35 lbs.	8 ppm	1
	Cucumber beetles	2 pts	—	30 lbs	8 ppm	1
		Do not apply unless plants are dry				
Pumpkins	Aphids Mites	1½ pts	—	30-35 lbs	8 ppm	3
	Leafhoppers	—	—	30-35 lbs	8 ppm	3
	Squash vine borers	3 pts	7 lbs	45 lbs	8 ppm	3
		Do not apply unless plants are dry				
Squash	Alfalfa loopers	For control of loopers, CYTHION should be used in combination with other recommended insecticides			8 ppm	7
	Aphids Spider mites	1½ pts	—	30-35 lbs	8 ppm	1
	Pickleworm	2 pts	5 lbs	35 lbs	8 ppm	1
	Squash vine borers Cucumber beetles	3 pts	7 lbs	45 lbs	8 ppm	1
		Do not apply unless plants are dry				
EGGPLANT	Aphids Spider mites	1 pt	2 lbs	—	8 ppm	3
	Lace bug	3 pts	—	—	8 ppm	3
GARLIC LEEKS SHALLOTS	Thrips Aphids	1½-2 pts	4 lbs	—	8 ppm	3
MUSHROOMS	Mites	2½ pts per 130 gals OR 1 lbs per 100 sq ft of bed	—	—	8 ppm	1
	Phorid & sciarid flies	2½ pts per 130 gals OR 1 lbs per 100 sq ft of bed	—	10-15 lbs OR 2 lbs per 60 ft single house	8 ppm	1
		Make thorough application as soon as possible after picking Repeat applications as necessary, usually twice a week				

Table 26. (Continued)

VEGETABLES

CROP	PEST	AMOUNT PER ACRE 57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
OKRA	Aphids	1½ pts.	6 lbs.	20-30 lbs.	NR	*
	Japanese beetle	2 pts.	5 lbs.	30 lbs.	NR	*
		*Do not apply after pods have started to form.				
ONIONS	Thrips	1½ pts.	4 lbs.	30-40 lbs.	8 ppm	3
	Onion maggots	2½ pts.	6 lbs.	40 lbs.	8 ppm	3
PEAS & PEA VINES FOR FORAGE	Pea aphid	1½ pts.	—	25-30 lbs.	8 ppm	*
	Pea weevil	1½-2 pts.	—	25-30 lbs.	8 ppm	*
		*Make no application within 7 days of harvest if vines are to be used for animal feeds. If vines are not to be fed application may be made within 3 days of harvest.				
PEAS	Alfalfa loopers Celery loopers	For control of loopers, CYTHION should be used in combination with other recommended insecticides.				
PEPPERS	Aphids	1 pt.	2 lbs.	—	8 ppm	3
	Pepper maggots	2½ pts.	6 lbs.	40 lbs.	8 ppm	3
POTATOES	Aphids Leafhoppers	1 pt.	2½ lbs.	30-35 lbs	8 ppm	0
	False chinch bug	1½ pts.	4 lbs	25 lbs.	8 ppm	0
	Mealybugs	1 pt	4 lbs.	30-35 lbs	8 ppm	0
ROOT CROPS Beets	Aphids	1½-2 pts.	—	—	8 ppm	7*
		*If tops are to be used as feed				
Carrots	Aphids	1½-2 pts.	2 lbs	30-35 lbs.	8 ppm	7
	Leafhoppers	2½ pts.	6 lbs.	40 lbs.	8 ppm	7
Horse-radish, Parsnips, Radishes, Salsify	Aphids	1½-2 pts.	2 lbs.	30-35 lbs.	8 ppm	7
Rutabagas	Aphids	1½ pts	—	—	8 ppm	3
Sweet potatoes	Leafhoppers	1½-2 pts.	2 lbs	25-30 lbs	NR	0
	Morning-glory leafminers	2½-3 pts	—	—	NR	0
Tomatoes (outdoor)	Spider mites	1½ pts.	2 lbs	35-45 lbs	8 ppm	1
	Aphids	1 pt.	2 lbs.	35-45 lbs	8 ppm	1
	Tomato russet mite	—	2-4 lbs.	35-45 lbs	8 ppm	1
	Drosophila	2½ pts.	6 lbs.	40 lbs.	8 ppm	1

FRUIT

CROP	PEST	AMOUNT 57% Emulsifiable Liquid/ 100 gal.	25% Wettable Powder/ 100 gal.	4% Dust	Residue Tolerance	Interval (days) between last application and harvest
APPLES*	Wooly apple aphid Bud moth	1 pt.	2 lbs	—	8 ppm	3
	Green apple aphid	1½ pts.	2 lbs.	—	8 ppm	3
	Rosy apple aphid	1½ pts	2½ lbs.	—	8 ppm	3
	Mealybug	1-2 pts	2½ lbs.	—	8 ppm	3
	Codling moth Plum curculio Red-handed leaf roller	2 pts.	3 lbs	—	8 ppm	3
	Forbes scale	1 pt	2½ lbs	—	8 ppm	3
	Putnam scale San Jose scale	—	2-2½ lbs.	—	8 ppm	3
	Tent caterpillars	1-1½ pts	2½-4 lbs	—	8 ppm	3
	Bagworms	—	3 lbs	—	8 ppm	3
	Leafhoppers	—	2 lbs.	—	8 ppm	3
	Unspotted tentiform leaf miner	—	2 lbs	—	3 ppm	3
	Yellow-necked caterpillars	—	2 lbs	—	8 ppm	3
		*Consult local spray schedules for recommended combinations of CYTHION with other insecticides for control of insect complex on apples CYTHION EMULSIFIABLE LIQUID MAY CAUSE INJURY TO McINTOSH AND CORTLAND VARIETIES				
APPLES (Dormant and delayed dormant sprays)	Wooly apple aphid Green apple aphid Rosy apple aphid Mites Red-banded leaf roller	1 pint of 57% emulsifiable liquid plus 1 gallon of superior oil per 100 gals. of water OR 2 lbs. of 25% wettable powder plus 1 gallon of superior oil per 100 gals. of water MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
	Forbes scale Putnam scale San Jose scale	4 lbs. of 25% wettable powder plus 2 gals. superior oil per 100 gals. of water MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
APRICOTS	Codling moth Orange tortrix Terrapin scale Soft brown scale Aphids	1½-2 pts	4 lbs	—	8 ppm	7

Table 26. (Continued)

FRUIT

CROP	PEST	AMOUNT 57% Emulsifiable Liquid/100 gal.	 25% Wettable Powder/100 gal.	 4% Dust	Residue Tolerance	Interval (days) between last application and harvest
AVOCADOS	Latania scale Greenhouse thrips Omniverous looper Orange tortrix Soft brown scale	1½ pts.	3 lbs	—	8 ppm	7
CHERRIES	Black cherry aphid	1½ pts.	2 lbs	—	8 ppm	3
	Fruit tree leaf roller	1½ pts.	—	—	8 ppm	3
	Cherry fruit fly Bud moth	1 pt	2 lbs	—	8 ppm	3
	Lesser peach tree borer	—	4 lbs.	—	8 ppm	3
	San Jose scale Forbes scale	—	2-2½ lbs.	—	8 ppm	3
		INJURY MAY OCCUR ON CERTAIN VARIETIES OF SWEET CHERRIES PARTICULARLY IN THE NORTHWEST				
CHERRIES (Dormant and delayed dormant sprays)	Aphids Scale insects	2 lbs. of 25% wettable powder plus 1 gal. superior oil per 100 gals. of water OR 3 lbs. of 25% wettable powder plus 2 gals. superior oil per 100 gals. of water MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
CITRUS		CONSULT LOCAL SPRAY SCHEDULES FOR RECOMMENDED VOLUMES OF SPRAY PER ACRE				
Grapefruit, Lemons, Limes, Oranges, Tangerines, Tangelos, Kumquats	California red scale Yellow scale Purple scale Black scale (single & off brooded) Soft scale Citricola scale	1-1½ pts	2½-3½ lbs	—	8 ppm	7
	Florida red and purple scales (light & medium infestations)	2 pts	3-5 lbs	—	8 ppm	7
	Thrips	1½ pts / 200 gals / acre	6 lbs / 200 gals / acre	—	8 ppm	7
	Green citrus aphid	—	1-2 lbs	—	8 ppm	7
	Mediterranean fruit fly	—	2-3 lbs. per acre	—	8 ppm	3
		Add 1 lb. of yeast hydrolyzate or 1 quart of sauce base #2.				
		MAKE NO APPLICATIONS WHEN TREES ARE IN BLOOM				

FRUIT

CROP	PEST	AMOUNT 57% Emulsifiable Liquid/100 gal.	 25% Wettable Powder/100 gal.	 4% Dust	Residue Tolerance	Interval (days) between last application and harvest
Dates	Nitidulid beetles	—	—	Apply thoroughly to each cluster	8 ppm	7
FIGS	Dried fruit beetles Vinegar beetles	2 qts. plus 1-2 gals unsulfurized molasses per acre	—	50 lbs	8 ppm	3
GRAPES*	Leafhoppers	1½ pts	1-1½ lbs	20-40 lbs + sulfur	8 ppm	3
	Spider mites	1½ pts	—	20-40 lbs + sulfur	8 ppm	3
	Mealybugs	1½ pts	—	—	8 ppm	3
	Japanese beetle	—	2 lbs / 100 gals	—	8 ppm	3
	Terrapin scale	1½ pts	—	—	8 ppm	3
	Drosophila (vinegar or pomace fly)	—	—	25-35 lbs	8 ppm	3
		NOTE: RATES ARE PER ACRE IN SUFFICIENT WATER FOR THOROUGH COVERAGE				
		INJURY MAY OCCUR ON GRAPES OF RIBIER, ITALIA, CARDINAL AND ALMERIA VARIETIES WHEN SPRAYS CONTAINING CYTHION ARE APPLIED AFTER THE CLUSTERS APPEAR				
	▶	*See Stored Product Section for protection of raisins.				
NURSERY STOCK GRAPE VINES	Overwintering grape phylloxera	For the control of overwintering grape phylloxera on nursery stock grape vines, remove excess soil from the roots and dip in a solution made up of 1 to 1½ pints of CYTHION 57% emulsifiable liquid in 50 gallons of water. Submerge the entire root system in the solution for 5 minutes. Keep the solution agitated at all times. Fifty gallons of solution will treat approximately 500 nursery stock grape vines.				
MANGO, PASSION FRUIT & GUAVA (Hawaii)	Fruit flies	—	2 lbs / 10-40 gal 3 lbs 40-150 gal	—	8 ppm	2
		Add 1 lb. partially hydrolized yeast protein or enzymatic yeast hydrolyzate to CYTHION spray per acre. For applications to less than 1 acre, use 15 tbs. of 25% WP per 5 gals. of water plus 10 tbs. of partially hydrolized yeast protein or enzymatic yeast hydrolyzate.				

Table 26. (Continued)

FRUIT

FRUIT

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CROP	PEST	AMOUNT 57% Emulsifiable Liquid/ 100 gal.	 25% Wettable Powder/ 100 gal.	 4% Dust	Residue Tolerance	Interval (days) between last application and harvest
NECTARINES	Plum curculio	2 pts.	3 lbs.	—	8 ppm	7
	Mites	1-2 pts	2½ lbs	—	8 ppm	7
	Parlatoria scale	—	2 lbs. + 1 gal. light-medium oil*	—	8 ppm	7
		*Application of this mixture should be made only in the petal fall period				
		CYTHION MAY CAUSE FRUIT SPOTTING ON NECTARINES				
PEACHES	European red mite Two-spotted mite	—	2-2½ lbs	—	8 ppm	7
		Make 2 or more applications as needed				
	Oriental fruit moth Plum curculio	2 pts	3 lbs	—	8 ppm	7
	San Jose scale (Calif. only)	—	See Note	—	—	—
		NOTE Prepare tank mix of 3 pounds 25% wettable powder plus 2 gallons oil emulsion and 4 pounds fixed copper per 100 gallons of water. Apply only when trees are dormant.				
	Green peach aphid Black cherry aphid Black peach aphid Rusty plum aphid Japanese beetle	1 pt	2 lbs	—	8 ppm	7
	Lesser peach tree borer	—	4 lbs	—	8 ppm	7
	Terrapin scale Cottony peach scale	2 pts	2-2½ lbs	–	8 ppm	7
PEACHES (Dormant and delayed dormant sprays)	Aphids	2 lbs. of 25% wettable powder plus 1 gal. superior oil per 100 gals. water				
	Peach twig borer Scale insects	3 lbs. of 25% wettable powder plus 2 gals. superior oil per 100 gals. water				
		MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
PEARS (cont. next pg.)	Mealybug Mites Pear psylla	1-2 pts	2-2½ lbs	—	8 ppm	1
	Codling moth Plum curculio	2 pts	3 lbs		8 ppm	1

CROP	PEST	57% Emulsifiable Liquid/ 100 gal.	25% Wettable Powder/ 100 gal.	4% Dust	Residue Tolerance	Interval (days) between last application and harvest
PEARS (continued)	Fruit tree leaf roller Red-banded leaf roller	2 pts	3 lbs	—	8 ppm	1
	Apple aphid Apple grain aphid	—	2 lbs		8 ppm	1
	Forbes scale San Jose scale	—	2-2½ lbs	—	8 ppm	1
PEARS (Dormant and delayed dormant sprays)	Aphids Leaf rollers Pear psylla	2 lbs. of 25% wettable powder plus 1 gal. superior oil per 100 gals. water				
	Scale insects	3 lbs. of 25% wettable powder plus 2 gals. superior oil per 100 gals. water				
		MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
PINEAPPLE	Mealybug	1 gal. per acre	20 lbs. per acre	160 lbs.	8 ppm	7
PLUMS & PRUNES	Mealy plum aphid	1 pt	1 lb.	—	8 ppm	3
	Plum curculio Mealy plum aphid	CYTHION should be used in combination with other recommended insecticides to control all insect pests				0
	Lesser peach tree borer	—	4 lbs		8 ppm	3

Table 25. (Continued)

FRUIT

CROP	PEST	AMOUNTS 57% Emulsifiable Liquid/ 100 gal.	25% Wettable Powder/ 100 gal.	4% Dust	Residue Tolerance	Interval (days) between last application and harvest
PLUMS & PRUNES	European red mite Two-spotted spider mite	—	2-3 lbs	—	8 ppm	3
		Apply in summer, repeat after 7-10 days if needed				
	Prunes: San Jose scale (Calif. only)	—	See note	—	—	3
	Prunes: bud moth	1 pt	2 lbs	—	8 ppm	3
		NOTE: Prepare tank mix of 3 pounds 25% wettable powder plus 2 gallons oil emulsion and 4 pounds of fixed copper per 100 gallons of water. Apply only when trees are dormant.				
PLUMS & PRUNES (Dormant and delayed dormant sprays)	Scale insects	1 pt. of 57% emulsifiable liquid plus 1 gal. superior oil per 100 gals. of water OR 3 lbs. of 25% wettable powder plus 2 gals. superior oil per 100 gals. of water				
	Aphids	2 lbs. of 25% wettable powder plus 1 gal. superior oil per 100 gals. water				
		MAKE FULL COVERAGE DORMANT OR DELAYED DORMANT SPRAYS ONLY				
QUINCES	Plum curculio Codling moth Oriental fruit moth	2 pts	3 lbs.	—	8 ppm	3
	Forbes scale	1 pt	2½ lbs.	—	8 ppm	3
	Mites	1-2 pts	2-2½ lbs.	—	8 ppm	3

BERRIES

CROP	PEST	AMOUNT PER ACRE 57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest
BLACKBERRIES, BOYSENBERRIES, DEWBERRIES, LOGANBERRIES, RASPBERRIES	Mites Thrips Leafhoppers	1½ pts	2 lbs	—	8 ppm	1
	Japanese beetle	1½ pts	4 lbs	—	8 ppm	1
	Aphids Rose scale	3 pts	7 lbs	40-50 lbs	8 ppm	1
RASPBERRIES	Sap beetle	1½-2 pts	4-5 lbs	—	8 ppm	1
BLUEBERRIES	Cranberry fruit worm	—	2 lbs	—	8 ppm	1
	Cherry fruit worm	—	4 lbs	—	8 ppm	1
	Blueberry maggot	See Note	—	25 lbs	8 ppm	0
		NOTE: Blueberry maggots in the Northeast: 1 pt. of 57% emulsifiable liquid or 2 lbs. of 25% wettable powder plus 1½ qts. of Staley's Sauce Base #7 in 100 gals. of water per acre and apply by ground or air equipment. Pre-harvest interval — 8 hours.				
	Plum curculio Sharp-nosed leafhopper	—	6-8 lbs	40-50 lbs	8 ppm	1
	Japanese beetle	1½ pts	—	25 lbs	8 ppm	1

Table 26. (Continued)

BERRIES

AMOUNT PER ACRE

CROP	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust	Residue Tolerance	Interval (days) between last application and harvest
CRANBERRIES	Leafhoppers Black-headed fireworm	1½ pts.	2½ lbs.	30-50 lbs	8 ppm	3
	Spittlebug nymphs Cranberry fruitworms	1½ pts.	2½ lbs.	—	8 ppm	3
	DO NOT APPLY CLOSE TO OR DURING THE BLOOM OR BERRY-SET PERIOD DO NOT APPLY WHEN FOLIAGE IS WET					
CURRANTS GOOSE-BERRIES	Mites	—	2 lbs.	—	8 ppm	3
	Japanese beetle	—	4 lbs.	—	8 ppm	3
	Currant aphid	—	8 lbs.	—	8 ppm	3
	Imported currantworm	—	8 lbs.	—	8 ppm	3
STRAW-BERRIES	Aphids Spider mites	1½ pts.	2½ lbs.	40 lbs.	8 ppm	3
	Strawberry root weevil	1½ pts. Apply to soil surface before planting and work into top 6 to 8 inches	4-6 lbs.	25-40 lbs	8 ppm	3
	Lygus bug Spittlebugs Field crickets Thrips	1½-3 pts	4-8 lbs	25-50 lbs.	8 ppm	3
	Potato leafhopper Strawberry leaf-roller Whiteflies	1½-2½ pts	4-6 lbs.	25-40 lbs	8 ppm	3

NUTS

[illegible]

CROP	PEST	57% Emulsifiable Liquid/ 100 gal.	25% Wettable Powder/ 100 gal.	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
ALMONDS	Aphids Red spiders	1-2 pts.	2-2½ lbs	—	NR	0
	Peach twig borer	1-1½ pts.	3-4 lbs	—	NR	0
		No more than 8 lbs. of actual CYTHION per acre should be applied to almond trees				
CHESTNUTS	Mites	—	2 lbs	—	NR	—
		Do not apply after shucks begin to open. Do not graze livestock in treated groves				
FILBERTS	Filbert aphid Apple mealybug Eye-spotted bud moth	1 pt	2 lbs	50 lbs	NR	0
	Scale (crawler stage) Tingids	1 pt.	2 lbs	—	NR	0
MACADAMIA NUTS	Green stink bugs	1½ pts	4 lbs May be applied during harvest	—	NR	0
PECANS (cont. next pg.)	Spider mites Aphids	1-2 pts.	2-3 lbs	—	8 ppm	0

NUTS

		AMOUNT				
CROP	PEST	57% Emulsifiable Liquid/ 100 gal.	25% Wettable Powder/ 100 gal.	4% Dust	Residue Tolerance	Interval (days) between last application and harvest or grazing
PECANS	Pecan nut casebearer	—	3 lbs.	100 lbs.	8 ppm	0
	Pecan leaf casebearer Pecan phylloxera	—	3 lbs.	—	8 ppm	0
	Pecan bud moth	—	3 lbs.	10 lbs. by airplane	8 ppm	0
WALNUTS	Walnut husk fly	—	8-10 lbs.*	—	8 ppm	0
		*Per 500 gals. per acre by air-carrier type equipment. 1-1½ lbs. per 100 gals. by conventional high pressure spray equipment				
		Bait Sprays. Combine Staley's sauce base #2 or #7 (2 qts. per acre) to above dosages				
	Aphids	—	4-8 lbs.*	40-60 lbs.	8 ppm	0
		*Per 400 gals. per acre by air-carrier type equipment. ½-1 lb. per 100 gals. by conventional high pressure spray equipment				
	Mites		4-8 lbs.*	—	8 ppm	0
		*Per 400 gals. per acre by air-carrier type equipment. ½-1 lb. per 100 gals. by conventional high pressure spray equipment				

ORNAMENTALS

INJURY MAY OCCUR ON FERNS, HICKORY, VIBURNUM LANTANA, CRASSULA AND CANAERTI JUNIPER FOLLOWING THE USE OF EMULSIFIABLE LIQUID AND WETTABLE POWDERS. SLIGHT INJURY HAS ALSO BEEN REPORTED ON BOSTON, PTERIS AND MAIDENHAIR FERNS, PETUNIAS, SMALL-LEAF SPIREA, WHITE PINE AND MAPLES. UNDER EXTREME HEAT, DROUGHT AND DISEASE CONDITIONS THE EMULSIFIABLE CONCENTRATES MAY CAUSE SLIGHT DAMAGE TO ELMS.

PLANT	PEST	57% Emulsifiable Liquid/100 gal.	25% Wettable Powder/100 gal.	4% Dust
ORNAMENTALS (See directions for mixing small quantities, pg. 3)	Oyster shell scale	1 pt.	—	—
		Apply when scale crawlers have settled on foliage		
	Lace bug	1 pt.	4 lbs.	—
	Euonymus scale	1-1½ pts.	—	—
	Aphids	1½ pts.	2½ lbs.	See Note
	Mealybugs	1½ pts.	2½ lbs.	—
	Spider mites	1½ pts.	2½ lbs.	See Note
	Whitefly	1½ pts.	2½ lbs.	—
	Four-lined leaf bug Japanese beetle adult Potato leafhopper Tarnished plant bug Thrips Rose leafhopper European pine shoot moth Scurfy scale	1½ pts.	—	—
		NOTE. Apply sufficient amount for good coverage		
	Birch leaf miner Boxwood leaf miner	2 pts.	—	—
	Bagworms	2 pts.	4 lbs.	See Note
	Tent caterpillar	2 pts.	2 lbs.	—
	Azalea scale Oak kermes* Pine leaf scale Magnolia scale	2 pts.	—	—

*Apply when scale crawlers have settled on foliage

Table 26. (Continued)

ORNAMENTALS

PLANT	PEST	AMOUNT		
		57% Emulsifiable Liquid/100 gal.	25%Wettable Powder/100 gal.	4% Dust
ORNAMENTALS (See directions for mixing small quantities, pg. 3)	Fletcher scale*	2 pts.	3 lbs.	—
	Florida red scale* Juniper scale*	2 pts.	6 lbs.	—
		*Apply when scale crawlers have settled on foliage.		
	Black scale crawlers	2¼ pts	6 lbs.	—
	Monterey pine scale Soft scale	2½ pts.	6 lbs.	—
	Pine needle scale	4 pts	4 lbs.	—
	Wax scale	2 qts	Apply in spring when crawlers are active. Repeat 1 or 2 full coverage applications at 10 day intervals.	
		NOTE Apply sufficient amount for good coverage		
GREENHOUSE (in and around greenhouses and gardens)	Millipedes Springtails Sowbugs	Mix 1 teaspoonful of 57% E.L. in 1 gal. of water and apply to 150 square feet of soil surface or where insects congregate OR apply dust at the rate of 1 lb. per 150 square feet of soil surface or where insects congregate. Repeat at 7-10 day intervals as needed		
ROSES, CHRYSANTHEMUMS, CARNATIONS	Aphids Whiteflies Mealybugs Thrips Two spotted mite	Apply one pound of 15% aerosol per 50,000 cubic feet.		

LIVESTOCK

PRECAUTIONS FOR USE OF CYTHION ON LIVESTOCK:

DO NOT TREAT ANIMALS UNDER ONE MONTH OF AGE.

WHEN APPLYING SPRAYS AND DUSTS, AVOID CONTAMINATION OF FEED, FOOD CONTAINERS AND WATERING TROUGHS.

DO NOT APPLY TO LACTATING DAIRY ANIMALS OR NON-LACTATING DAIRY ANIMALS WITHIN TWO WEEKS OF FRESHENING UNLESS OTHERWISE NOTED.

RESIDUE TOLERANCE 4 ppm in or on meat and meat by-products. (Uses on dairy cattle subject to pending petition.)

		AMOUNT		
	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust
CATTLE (Beef & Non-milking) HORSES	Lice	1 gal. per 100 gals. OR 6½ ozs. per 5 gals.*	16 lbs. per 100 gals. OR ¾ lb. per 5 gals.*	•
		*Treat animals thoroughly		
	Ticks	1-2 gals. per 100 gals OR 6½-13 ozs. per 5 gals.*	16-32 lbs. per 100 gals. OR ¾-1½ lbs. per 5 gals.*	•
		*Treat animals thoroughly Repeat applications at 2 week intervals if needed		
	Horn fly	1-1½ gals. per 100 gals OR 6½-10 ozs. per 5 gals	16-24 lbs. per 100 gals OR ¾-1¼ lbs. per 5 gals.	4 lbs. per animal*
	*Apply on back and neck of the animals and repeat applications at 10-14 day intervals.			
	BACK RUBBING DEVICES	For the reduction of lice, apply a mixture of 2% CYTHION (using CYTHION 57% emulsifiable liquid) in fuel oil. There may also be a reduction in horn flies. These devices should be made continuously accessible one to each 35-45 head of cattle and re-treated every 2-3 weeks. DO NOT MAKE ACCESSIBLE TO LACTATING DAIRY ANIMALS OR NON-LACTATING DAIRY ANIMALS WITHIN 2 WEEKS OF FRESHENING.		

Table 26. (Continued)

LIVESTOCK

AMOUNT

	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust
CATTLE Dairy	Horn fly	—	—	4 tbs. per animal
	Apply on back and neck of the animals and repeat applications at 10-14 day intervals.			
	DO NOT APPLY TO DAIRY CATTLE LATER THAN 5 HOURS BEFORE MILKING OR DURING MILKING. DO NOT SPRAY OR DIP DAIRY ANIMALS IN CYTHION. RESIDUE TOLERANCE: 0 ppm in milk.			
HOGS	Lice	1 gal. per 100 gals. OR 6½ ozs. per 5 gals.*	16 lbs. per 100 gals. OR ¾ lb. per 5 gals.*	•
		*Treat animals, pens, and litter thoroughly.		
	Sarcoptic mange	1 gal. per 100 gals. OR 6½ ozs. per 5 gals.	16 lbs. per 100 gals. OR ¾ lb. per 5 gals.	—
	Use extreme care to cover all body surfaces including the inside of the ears. Second treatment may be necessary in 10 days. HOGS SHOULD BE KEPT OUT OF SUN AND WIND FOR A FEW HOURS AFTER TREATMENT.			
SHEEP & GOATS	Lice Ticks Keds	1 gal. per 100 gals. OR 6½ ozs. per 5 gals.*	16 lbs. per 100 gals. OR ¾ lb. per 5 gals.*	—
		*Treat animals thoroughly. Repeat application after 2 or 3 weeks if needed.		
		DO NOT APPLY TO MILK GOATS.		

POULTRY

PRECAUTIONS FOR USE OF CYTHION ON POULTRY:

AVOID CONTAMINATION OF FEED AND FEEDING TROUGHS AND WATER FOUNTAINS WITH SPRAYS OR DUST.

WHEN USING EMULSIFIABLE LIQUID AND POWDER, USE A HIGH PRESSURE SPRAYER FOR SURFACE SPRAYS.

RESIDUE TOLERANCE: POULTRY—4 ppm in or on meat and meat by-products. EGGS—0 ppm

	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust
CHICKENS, DUCKS, GEESE AND TURKEYS Direct application	Northern fowl mite Poultry lice Chicken red mite*	2 tbs. per 1 gal. water per 100-150 birds	2½ oz. per 1 gal. water per 100-150 birds.	Dust individual birds with a shaker can or rotary hand duster.
		Repeat application in 4-8 weeks or when necessary.		
	*As a supplement to premise treatment for chicken red mite.			
Tail-dipping	Northern fowl mite Chicken body lice Shaft lice	8½ ozs. per 15 gals. water per 400 birds. Hold bird by wings and dip 3 to 4 inches of tail into solution. Treat vent and surrounding areas.	—	—
		Repeat in 7-10 days if necessary.		
Roost paint	Chicken red mite Poultry lice	2-7 ozs. per 1 gal. water.	—	—
		Brush on at rate of 1 pt. per 150 ft. of roost.		
Premise treatments (cont. next pg.)	Northern fowl mite Chicken red mite Poultry lice Flies	4 tbs. per 1 gal. water.	5 oz. per 1 gal. water.	(Northern fowl mite, Chicken red mite, Poultry lice) 1 lb. per 50-60 sq. ft. of litter and floor space and to nests, roosts, and adjacent areas. Apply with a rotary hand duster, puff duster or by sprinkling from can or other container.
		Apply liberally to litter, walls, ceilings, roost nests and adjacent areas. Force spray into cracks and crevices.		

Table 26. (Continued)

POULTRY

		AMOUNT		
	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust
Premise treatments	Poultry ticks	6-7 ozs. per 1 gal. water. Apply liberally to walls, ceilings and adjacent areas. Force spray into cracks and crevices.	—	—
Range treatments	Chiggers	½ pt. per acre	—	25 lbs. per acre.
	Treat range thoroughly day before placing poultry on range. Repeat every 2-3 weeks.			
Dust bath boxes	Northern fowl mite Poultry lice	—	—	1 lb. dust per box (18" x 12" x 3") per 30 hens. Remove boxes when dust has been used
Dust bath boxes, Natural soil wallows	Stick tight flea	—	—	15 lbs. per box (2' x 3' x 1') per 100 birds OR Apply in natural soil wallows at the rate of 7½ lbs. per 50 birds
Range pens	Stick tight flea	—	—	1 lb. per 20 sq. ft. of surface
	Repeat in 28 days and then as often as necessary.			
Brooder house	Stick tight flea on brooder house chicks	—	—	2 lbs. per 100 chicks.
	Distribute the dust evenly in each corner of the brooder house.			

DOMESTIC PETS

DO NOT APPLY DIRECTLY TO DOGS AND CATS UNDER ONE MONTH OF AGE

	PEST	57% Emulsifiable Liquid	25% Wettable Powder	4% Dust
DOGS & CATS	Fleas	1 oz. per gal. water	—	Make complete coverage.
		Wet the animals throughly using a hand sprayer. Repeat treatments may be used within 2 to 3 weeks.		
PET QUARTERS, YARDS AND LAWNS	Fleas	5 oz. per gal. water Use 1 gal. per 1,000 sq. ft. of surface	—	1-2 lbs. per 1,000 sq. ft. of surface.
		Remove manure or debris before treating. Repeat treatment within 3 to 4 weeks if necessary.		

Table 26. (Continued)

HEAD AND BODY LICE ON HUMANS

Apply by means of a hand or power duster, CYTHION 1% dust to head, cap, sleeves, the back through the neck opening along the seams of clothing thoroughly and to the crotch from front to rear. Pat clothing thoroughly over the body to assure maximum distribution of the dust.

One ounce of CYTHION 1% dust is sufficient to thoroughly treat an adult fully clothed. Sprinkle excess dust over bed clothing, blankets and other possible louse habitats. Repeat at 2 week intervals until infestation is eliminated.

HOMES, DAIRIES, FOOD PROCESSING PLANTS

CAUTION: CYTHION SPRAYS MAY DAMAGE FINISHED SURFACES AND FABRICS. AVOID CONTAMINATION OF FOOD, UTENSILS, MILK, MILK EQUIPMENT, AND WATER. DO NOT USE IN MILK PROCESSING ROOMS.

ANTS, CRICKETS, CLOVER MITES, EARWIGS, PANTRY PESTS*, SCORPIONS, SILVERFISH, SPIDERS

In and about homes, dairies and food processing plants, use CYTHION 3% in either water or deodorized kerosene, or CYTHION 3% pressurized spray.

To make water solution – dilute 3 tablespoonfuls of CYTHION 57% emulsifiable liquid in 1 quart of water, or 6⅔ ounces per gallon.

To make oil solution – dilute 1 part of CYTHION 57% emulsifiable liquid in 19 parts of a mixture consisting of 4 parts kerosene type solvent and 1 part aromatic hydrocarbon type solvent.

Apply by means of a coarse spray, paint brush, or pressurized spray to window sills, baseboards, drainboards, under sinks, stoves, cracks, crevices, and to other areas frequented by insects.

Apply CYTHION 4% dust liberally to window sills, cracks and crevices, around doors, baseboards, storage areas, bookcases, under sinks and to other areas frequented by these pests.

CENTIPEDES, SCORPIONS

Apply CYTHION 4% dust liberally to window sills, cracks and crevices, around doors, baseboards, storage areas, bookcases, under sinks and to other areas frequented by these pests.

FLEAS, BROWN DOG TICKS

Apply CYTHION 4% dust liberally to floors, cracks and crevices, sleeping quarters of animals, and to other areas frequented by these pests.

FLEAS, LICE, TICKS, AND OTODECTIC MANGE ON DOGS AND CATS

Fleas, Lice, and Ticks: Apply CYTHION 5% pressurized spray for 25 to 30 seconds per 18 to 20 pound dog, and for 15 seconds per 5 to 8 pound cat. Spray from tail to neck, legs, and under body. Repeat treatment in 7 days, if necessary. Wash hands after pressurized spray applications.

Otodectic Mange (Ear mite): Clean the infested ears and apply CYTHION 5% pressurized spray to ears only. Repeat treatment in 7 days if necessary. Wash hands after pressurized spray applications.

BEDBUGS

Use CYTHION 57% emulsifiable liquid at the rate of 2 to 4 tablespoonfuls per gallon of deodorized kerosene.

Apply lightly to all mattress surfaces in sufficient quantity to "mist" the fabric and generously to beds and woodwork, with special care taken to wet all possible hiding places.

CARPET BEETLES, CLOTHES MOTHS

Use a CYTHION 3% water or oil-based spray or CYTHION 3% pressurized spray.

Apply to baseboards, floors (including areas under carpets, along margins of carpets and in closets), behind radiators and other lint accumulation areas, closet shelves and walls, and infested surface areas of carpeting.

Application of 3% oil or water spray or low pressure spray to the areas mentioned above will also control clothes moth larvae in these locations.

If clothing or woolen goods are to be protected from clothes moth attack, they should receive regular treatments with a suitable mothproofing material.

ROACHES

In and about homes, dairies and food processing plants, use CYTHION 3% in either water or deodorized kerosene, or CYTHION 3% pressurized spray.

To make water solution – dilute 3 tablespoonfuls of CYTHION 57% emulsifiable liquid in 1 quart of water (6⅔ ounces per gallon).

To make oil solution – dilute 1 part of CYTHION 57% emulsifiable liquid in 19 parts of a mixture consisting of 4 parts kerosene type solvent and 1 part aromatic hydrocarbon type solvent.

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*Pantry pests such as the exposed stages of saw-toothed grain beetle, flour beetle, rice weevil, cigarette beetle, drug store beetle, and Indian meal moth.

Table 26. (Continued)

Apply by means of a coarse spray, paint brush, or low pressure spray to window sills, baseboards, drainboards, under sinks, stoves and to other areas frequented by insects.

Apply CYTHION 4% dust liberally to window sills, cracks and crevices, around doors, baseboards, storage areas, bookcases, under sinks and to other areas frequented by these pests. Spray surfaces until wet. Repeat applications as necessary. Care should be taken to thoroughly treat all cracks and crevices.

Use a CYTHION 1%, 2% or 4% aerosol containing a knockdown agent.

- AVOID PROLONGED OR REPEATED CONTACT WITH SKIN WHEN USING AEROSOLS.
- WASH THOROUGHLY AFTER USING AEROSOLS.
- KEEP OUT OF REACH OF CHILDREN.
- REMOVE FISH FROM ROOM BEFORE APPLYING AEROSOLS.
- AVOID APPLYING DIRECTLY TO ORNAMENTAL PLANTS IN THE HOME.

ANT MOUNDS

Use 1½ pts. of CYTHION 57% emulsifiable liquid or 3 lbs. of 25% wettable powder in 100 gallons of water.

Spray ant hills thoroughly so that they are well soaked. For other small ants in flower beds, lawns, around trees, spray lightly in the infested areas.

Repeat in 10-15 days if ants return.

LAWNS

For the control of ground pearls in lawns, apply CYTHION 57% emulsifiable liquid at the rate of 3 to 4 quarts or 16 pounds of CYTHION 25% wettable powder per acre in 100 gallons of water.

Make full coverage application to soil surface when ground pearl nymphs are in the pink, "crawler" or active stage and immediately wash into soil with additional water.

MOSQUITOES AND SMALL FLYING INSECTS

NOTE: CYTHION 57% EMULSIFIABLE LIQUID MAY CAUSE SPOTTING ON AUTOMOBILE PAINT FINISH. CARS SHOULD NOT BE SPRAYED DIRECTLY. IF ACCIDENTAL EXPOSURE OCCURS, THE CAR SHOULD BE WASHED IMMEDIATELY.

OUTDOORS: Use a CYTHION 2% to 5% area spray, fog or aerosol. As a 2% area or patio spray, dilute 57% emulsifiable liquid 1 part to 28 parts water. When using kerosene type solvents, such as fuel oil or diesel oil, as carriers, dilute 1 part 57% emulsifiable liquid in 20 parts of a mixture consisting of 4 parts kerosene type solvent and 1 part aromatic hydrocarbon type solvent. For 5%, dilute 1-11 using similar solvents. Repeat applications as necessary. Avoid applying oil based formulations to plants as injury may occur. CYTHION may be toxic to certain species of fish, particularly in shallow water.

Apply CYTHION 4% dust liberally around doors, windows, and porches and to other flat surfaces where pests are known to alight or congregate.

MOSQUITO LARVAE IN STANDING WATER: Apply CYTHION 57% emulsifiable liquid at the rate of 3 fluid ounces (approximately ¼ pound of actual CYTHION) per acre. Mix in sufficient water or oil to obtain even coverage when applied by air or ground equipment.

INDOORS: Use a CYTHION 2% liquid space and contact spray or a CYTHION pressurized spray or aerosol containing a knock-down agent.

Rooms should be thoroughly misted to envelop insects present and should be kept closed for 5 to 10 minutes. Sweep up and destroy fallen insects. Repeat applications as necessary.

- DO NOT CONTAMINATE FOOD, UTENSILS, MILK, MILK EQUIPMENT AND WATER.
- AVOID PROLONGED OR REPEATED CONTACT WITH SKIN WHEN USING AEROSOLS.
- WASH THOROUGHLY AFTER USING AEROSOLS.
- KEEP AWAY FROM HEAT, SPARKS AND OPEN FLAMES.
- KEEP OUT OF REACH OF CHILDREN.
- REMOVE FISH FROM ROOM BEFORE APPLYING AEROSOLS.
- AVOID APPLYING DIRECTLY TO ORNAMENTAL PLANTS IN THE HOME.

FLIES

For use in and around buildings which house domestic animals, around yards and meat processing plants. Do not use when plant is in operation. Cover all equipment and processing surfaces or wash thoroughly before use.

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Table 26. (Continued)

STRAIGHT CYTHION SPRAYS			BAIT SPRAYS (WITH SUGAR)	
Amount Spray	Amount Emulsifiable Liquid	OR Amount 25% Wettable Powder	Sugar	Add OR Molasses* or Corn Syrup
1 gal.	5 tbs.	–	7 tbs.	7 tbs.
2½ gals.	1 cup	1 lb.	1 cup	1 cup
12 gals.	1 qt.	5 lbs.	2½ lbs.	1 qt.
100 gals.	2 gals.	40 lbs.	20 lbs.	2 gals.

*Use unsulfurized molasses.

Apply as a spray at the rate of 1 gallon per 1,000 square feet on painted surfaces and 2 gallons per 1,000 square feet on unpainted surfaces where flies alight or congregate, such as walls, ceilings, stanchions, windows in dairy barns, fences, around garbage cans, etc.

As a floor treatment bait spray, use 5 ounces of CYTHION 57% emulsifiable liquid with 1 cup corn syrup or sugar in 2 gallons of water. As a spot treatment this mixture can also be applied to windows, stanchions, support beams, doors, etc. For control of fly maggots, apply as a bait spray over the surface of manure or poultry droppings. In loafing sheds, spray the dry bedding within 18 inches of the walls and around upright braces. For effective control in and around dairy barns and other agricultural premises, fly breeding sites such as manure and other waste materials should be eliminated. Do not apply to freshly whitewashed surfaces. Wait 14 days before applying. Repeat applications as necessary.

- AVOID CONTAMINATION OF MILK, MILK EQUIPMENT AND WATER.
- AVOID CONTAMINATION OF FEED AND FOOD PRODUCTS, ALSO DRINKING FOUNTAINS AND FEED TROUGHS.
- REMOVE LACTATING DAIRY ANIMALS FROM BUILDINGS BEFORE TREATING. ALSO REMOVE ANIMALS UNDER ONE MONTH OF AGE BEFORE TREATING.

DRY MILK PROCESSING PLANTS

- For the prevention of spread and the reduction of infestation of black carpet beetles and Trogoderma species, in plants processing dry milk.
- Mix 1 pt. of CYTHION 57% emulsifiable liquid or 1½ lbs. of CYTHION 25% wettable powder in 2½ gals. of water.
- Clean premises thoroughly before applying and maintain good sanitation at all times.
- Use spray equipment and nozzles that will produce a coarse spray.
- Application must be made only by an experienced or trained person.
- Apply as a residual spray to all sections of the plant and warehouses where insects hide or crawl such as cracks, corners, edges of floors, lower parts of walls, floors under storage platforms and underneath and behind protected places.
- Avoid contamination of milk, dry milk, equipment, utensils, work surfaces, containers and liners.
- Repeat application as necessary.

STORED GRAINS AND PEANUTS

GRAINS

For the protection of stored grains, such as wheat, oats, rice, corn, rye, barley, grain sorghum, and field or garden seeds, against confused flour beetle, rice weevil, granary weevil, saw-toothed grain beetle, flat grain beetle, red flour beetle, rusty grain beetle, lesser grain borer, Indian meal moth, and for control of cereal leaf beetles, apply CYTHION 57% emulsifiable liquid as follows:

RESIDUAL SPRAY — BEFORE STORING GRAINS: For a residual wall, floor, and machinery spray in grain elevators, in treating truck beds, box cars, and ships' holds before loading grain, apply 1 gallon of CYTHION 57% emulsifiable liquid per 25 gallons of water making thorough application. Before applying spray, clean elevators, box cars, etc. thoroughly. Remove and burn all sweepings and debris.

GRAINS GOING INTO STORAGE: Apply 1 pint of CYTHION 57% emulsifiable liquid in 2-5 gallons of water per 1000 bushels. Apply as the grain is being loaded or turned into final storage.

AFTER GRAINS ARE STORED: To protect stored grains from attack by Indian meal moth, apply CYTHION 57% emulsifiable liquid to the surface of clean or uninfested grain at the rate of ½ pint in 1-2 gallons of water per 1000 square feet of grain surface area. Apply the spray evenly over the surface of the grain. Apply immediately after grain is loaded into storage and repeat if necessary.

RESIDUAL SPRAY — BOX CARS FOR LOADING AND TRANSPORTING BAGGED FLOUR AND PACKAGED CEREALS: For the control of confused flour beetle, rice weevil, granary weevil, saw-toothed grain beetle, flat grain beetle, red flour beetle, rusty grain beetle, lesser grain borer, Indian meal moth and mite pests infesting empty box cars into which bagged flour and packaged cereals are to be loaded and transported, apply CYTHION 57% emulsifiable liquid as follows:

1. Clean the box cars thoroughly, then remove and burn all sweepings and debris.

2. Spray walls and floor to the point of run-off with either 1 gallon of CYTHION 57% emulsifiable liquid in 25 gallons of water, or one gallon of CYTHION 57% emulsifiable liquid in 10 gallons of deodorized kerosene. (The deodorized kerosene solution should be made up of 4 parts kerosene type solvent plus one part aromatic hydrocarbon type solvent.)

3. Let the sprayed box car stand empty with the doors open until the spray has thoroughly dried.

Table 26. (Continued)

4. Line the walls and floors of the box car with kraft paper before loading.

FIELD AND GARDEN SEEDS: Field and garden seeds can be protected against the above grain pests with a dosage of ⅓ pint of CYTHION 57% emulsifiable liquid in 1-2⅔ gallons of water per 500 bushels of seed.

CYTHION may be used under the requirements of the Khapra beetle quarantine, where water or diesel oil emulsions are indicated, as prescribed by the current quarantine instructions.

PEANUTS
For the control of stored peanuts against infestations of red flour beetle, Indian meal moth, confused flour beetle, rice weevil, flat grain beetle, rusty grain beetle, lesser grain borer, granary weevil and saw toothed grain beetle, apply CYTHION 25% wettable powder as follows:

RESIDUAL WAREHOUSE SPRAY – BEFORE STORING PEANUTS: Clean warehouse thoroughly of trash and remains of old peanuts 1-2 weeks before new peanut crop is stored. Then, thoroughly spray the interior of the empty warehouse, especially cracks and protected places. Treat outside walls to a height of 6-8 feet and the ground to a distance of 6 feet from the warehouse. Use 1 pint of CYTHION 57% emulsifiable liquid in sufficient water to make 2⅔ gallons of spray or, 1 gallon with 19 gallons of water. Apply as a coarse spray at the rate of 2 gallons per 1000 square feet of surface or to run-off.

BULK SPRAY TREATMENT – PEANUTS GOING INTO STORAGE: Use CYTHION 57% emulsifiable liquid at the rate of 2½ pints in 5 gallons of water for each 15 tons of farmers' stock peanuts as they go into storage.

Use good spray equipment. Apply coarse spray uniformly. Preferably, use a suitable mechanical spray applicator that regulates the rate of application to the flow of peanuts. Adjust the operating pressure of spray pump and size of nozzle opening to correlate the amount of spray delivery with the rate of flow of peanuts being treated. Avoid spraying with a fine mist that drifts away, by using low nozzle pressure. Shield the nozzle against wind and air currents.

AFTER PEANUTS HAVE BEEN BULK TREATED, USE CYTHION 25% WETTABLE POWDER AS A SUPPLEMENTAL SURFACE SPRAY AS FOLLOWS.

Use 1¼ pounds of CYTHION 25% wettable powder in 2 gallons of water for each 1000 square feet of surface.

Apply the first surface treatment as soon as the bin is filled and leveled, but not later than the first week in October. Apply the second surface treatment one month later, followed by subsequent treatments at 2-month intervals.

For applying the wettable powder surface treatments, use a piston pump type power sprayer, equipped with an agitator, and with a nozzle capable of delivering a coarse spray. Use spray equipment with sufficient capacity and power to cover large surfaces thoroughly.

STORED PRODUCTS

BAGGED CITRUS PULP

RESIDUAL WAREHOUSE SPRAY – BEFORE STORING: Before bagged citrus pulp is stored, thoroughly clean warehouses by removing and burning all debris and sweepings. Thoroughly spray with sufficient pressure the interior of empty warehouse (including cracks and protected places), outside walls to height of 6-8 feet, and the ground to a distance of about 6 feet from warehouse, by diluting 1 pint of CYTHION 57% emulsifiable liquid in sufficient water to make 2⅔ gallons of spray or, 1 gallon with 19 gallons of water.

Apply finished spray at the rate of 2 gallons per 1000 square feet of surface or to run off.

GOING INTO STORAGE: For the protection of bagged citrus pulp in storage against the cigarette beetle, saw-toothed grain beetle, confused flour beetle, red flour beetle, flat grain beetle, Indian meal moth, Angoumois grain moth, Mediterranean flour moth and the almond moth, use 12 ounces of CYTHION 25% wettable powder per gallon of water and apply at the rate of two gallons per 1000 square feet of exposed bag surface area when bagged citrus pulp is stored. Make two separate spray applications initially when bagged citrus pulp is stored. Once each month thereafter throughout storage period use 6 ounces per gallon of water and apply at the rate of two gallons per 1000 square feet of exposed bag surface area.

Do not use treated burlap bags other than for dried citrus pulp.

CATTLE FEED CONCENTRATE BLOCKS

For the protection of [illegible] cattle feed concentrate blocks in storage against cigarette beetle, use paper treated with CYTHION 57% emulsifiable liquid at the rate of 100 mg per square foot on the side next to the feed concentrate.

Use 4 fluid ounces of CYTHION 57% emulsifiable liquid per quart of water and apply to approximately 710 square feet of paper surface.

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MISCELLANEOUS

	CYTHION 57% Emulsifiable Liquid
DROSOPHILA FLIES & DRIED FRUIT BEETLES on and around Cull Fruit and Vegetable Dumps	For control of Drosophila flies and dried fruit beetles on and around cull fruit and vegetable dumps, mix 1½ gallons of CYTHION 57% emulsifiable liquid in 100 gallons of water and apply as a drench using 8-10 gallons of spray per 100 square feet. For best results, dumps should not be over 18 inches deep. DO NOT FEED TREATED FRUIT AND VEGETABLES.
	CYTHION 57% Emulsifiable Liquid
DROSOPHILA FLIES in and around Wineries and Processing Plants	For control of Drosophila flies in and around wineries and processing plants, paint all doors and window screens with a solution containing 3½ ounces of CYTHION 57% emulsifiable liquid in 1 quart of water. AVOID CONTAMINATION OF WINE, FOOD, UTENSILS, EQUIPMENT AND WATER.
	CYTHION 25% Wettable Powder
DROSOPHILA FLIES & DRIED FRUIT BEETLES on and around Cull Fruit and Vegetable Dumps	For control of Drosophila flies and dried fruit beetles on and around cull fruit and vegetable dumps, mix 32 pounds of CYTHION 25% wettable powder in 100 gallons of water and apply as a drench using 8-10 gallons of the spray per 100 square feet. For best results, dumps should not be over 18 inches deep. DO NOT FEED TREATED FRUIT AND VEGETABLES.

One treatment should give satisfactory protection of blocks against cigarette beetles for 3 months or one storage season.

Before nonmedicated cattle feed concentrate blocks are stored, thoroughly clean storage areas by removing and burning all debris and sweepings, then apply as a residual spray. 1 gallon of CYTHION 57% emulsifiable liquid per 25 gallons of water making thorough application.

RAISINS

For the protection of grapes (raisins) against the raisin moth, dried fruit beetle and vinegar fly during drying in the field, and for protection against the indian meal moth and saw-toothed grain beetle during storage, apply 3 to 3½ ounces of CYTHION 57% emulsifiable liquid per 144 square feet of paper used as drying trays (100-200 mg. actual CYTHION per square foot).

Raisins should be screened to remove dead insects and any other debris before storing.

Such treatment will protect raisins in storage for six months.

This information is presented in the form of the manufacturer's tables because it would be difficult, if not impossible, to improve on the quality of presentation of the registration data and use directions as set forth therein.

Since these tables were prepared, a number of uses of malathion previously registered on a "no residue - no tolerance" (NR) basis have been covered by finite tolerances. All tolerances established for malathion up to and including April 1974 have been included in Table 9, p. 57.

The malathion formulation ultra-low volume (ULV) concentrate, containing 95% of active ingredient (AI), equivalent to 9.7 lb AI/gal is intended for use, undiluted, in specially designed air or ground equipment capable of applying ULV of spray for use on the crops against various insects. (See Table 28.)

Due to its physical, chemical, and toxicological properties, malathion is well suited for the ULV method of application. It is estimated that the malathion ULV concentrate leads all other formulations in the total quantity of active ingredient applied in this form.

The registration data on malathion summarized in Tables 26 through 28 show that malathion is one of the most versatile insecticides available today. It is registered and recommended for use on a large number of agricultural, horticultural, ornamental and other crops; for the control of insect and mite pests affecting man and animals (including important disease vectors and other insects of public health importance); and for stored products. Thus, malathion is widely used not only in agriculture, but also by commercial, industrial and institutional organizations; in the home and garden field; and in insect abatement, quarantine and other control programs carried out by governmental agencies.

State Regulations - Malathion is one of the least toxic synthetic insecticides, rated only "slightly toxic" to humans and most other nontarget species. It is rapidly degraded after application. Due to these favorable properties, malathion is not currently subject to specific use restrictions under state pesticide laws or regulations.

Production and Domestic Supply of Malathion in the United States

Volume of Production - According to the United States Tariff Commission final report on synthetic organic chemicals,[1] there has been only one basic producer of malathion in the United States up to and including 1972, American Cyanamid Company.

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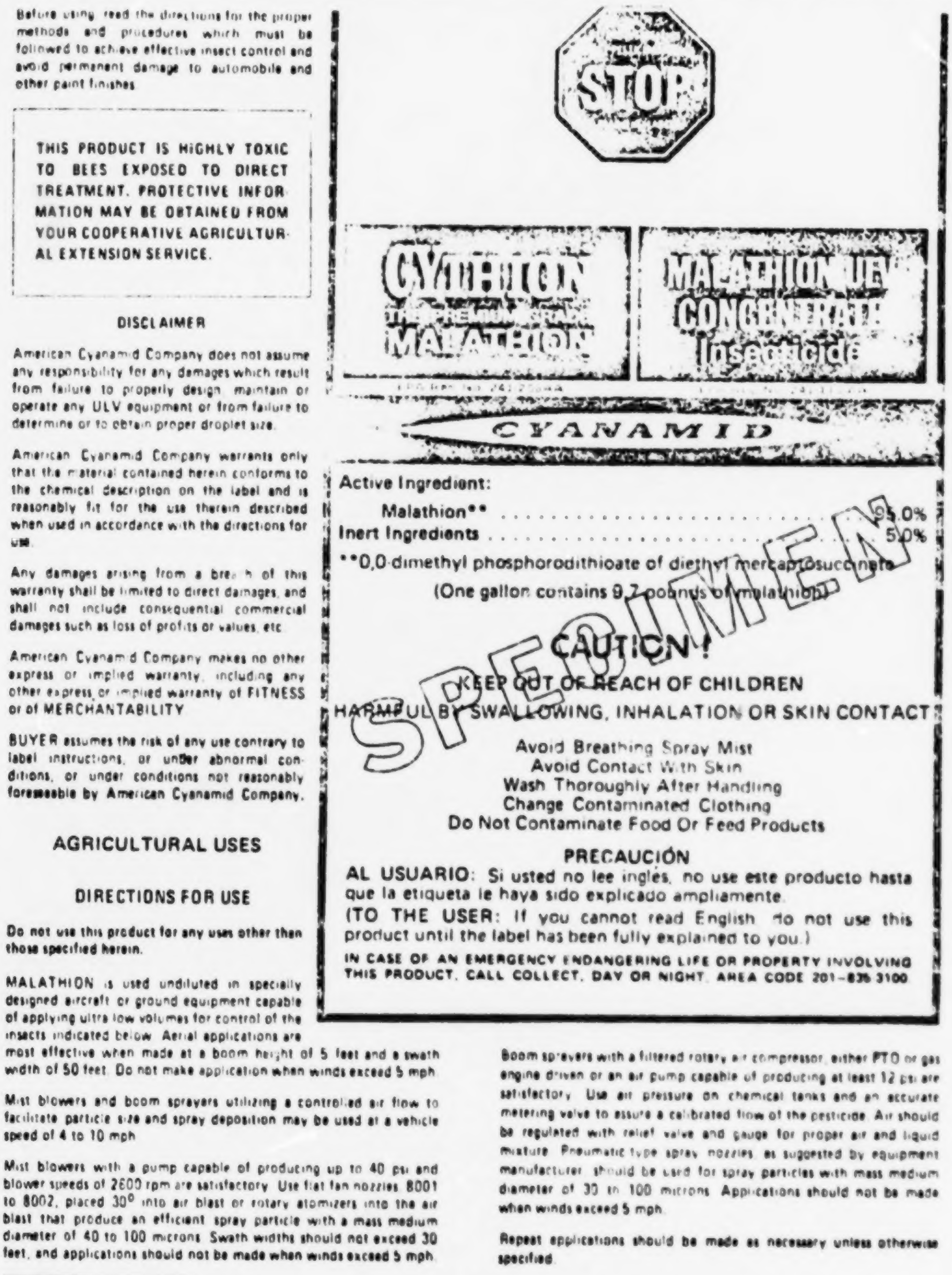
[1] U.S. Tariff Commission, Synthetic Organic Chemicals, U.S. Production and Sales, 1972, TC Publication 681 (1973).

Table 27. REGISTERED USES OF MALATHION ULV CONCENTRATE (Crops and Other Uses, Pests, Dosage Rates and Use Limitations)[a]


STOP
CYTHION
THE PREMIUM GRADE
MALATHION
MALATHION ULV
CONCENTRATE
Insecticide
CYANAMID
SPECIMEN

Active Ingredient:

Malathion**	95.0%
Inert Ingredients	5.0%

**0,0-dimethyl phosphorodithioate of diethyl mercaptosuccinate

(One gallon contains 9.7 pounds of malathion)

CAUTION!

KEEP OUT OF REACH OF CHILDREN

HARMFUL BY SWALLOWING, INHALATION OR SKIN CONTACT

Avoid Breathing Spray Mist
Avoid Contact With Skin
Wash Thoroughly After Handling
Change Contaminated Clothing
Do Not Contaminate Food Or Feed Products

PRECAUCIÓN

AL USUARIO: Si usted no lee ingles, no use este producto hasta que la etiqueta le haya sido explicado ampliamente.

(TO THE USER: If you cannot read English, do not use this product until the label has been fully explained to you.)

IN CASE OF AN EMERGENCY ENDANGERING LIFE OR PROPERTY INVOLVING THIS PRODUCT, CALL COLLECT, DAY OR NIGHT, AREA CODE 201-835-3100

Before using, read the directions for the proper methods and procedures which must be followed to achieve effective insect control and avoid permanent damage to automobile and other paint finishes.

THIS PRODUCT IS HIGHLY TOXIC TO BEES EXPOSED TO DIRECT TREATMENT. PROTECTIVE INFORMATION MAY BE OBTAINED FROM YOUR COOPERATIVE AGRICULTURAL EXTENSION SERVICE.

DISCLAIMER

American Cyanamid Company does not assume any responsibility for any damages which result from failure to properly design, maintain or operate any ULV equipment or from failure to determine or to obtain proper droplet size.

American Cyanamid Company warrants only that the material contained herein conforms to the chemical description on the label and is reasonably fit for the use therein described when used in accordance with the directions for use.

Any damages arising from a breach of this warranty shall be limited to direct damages, and shall not include consequential commercial damages such as loss of profits or values, etc.

American Cyanamid Company makes no other express or implied warranty, including any other express or implied warranty of FITNESS or of MERCHANTABILITY.

BUYER assumes the risk of any use contrary to label instructions, or under abnormal conditions, or under conditions not reasonably foreseeable by American Cyanamid Company.

AGRICULTURAL USES

DIRECTIONS FOR USE

Do not use this product for any uses other than those specified herein.

MALATHION is used undiluted in specially designed aircraft or ground equipment capable of applying ultra low volumes for control of the insects indicated below. Aerial applications are most effective when made at a boom height of 5 feet and a swath width of 50 feet. Do not make application when winds exceed 5 mph.

Mist blowers and boom sprayers utilizing a controlled air flow to facilitate particle size and spray deposition may be used at a vehicle speed of 4 to 10 mph.

Mist blowers with a pump capable of producing up to 40 psi and blower speeds of 2600 rpm are satisfactory. Use flat fan nozzles 8001 to 8002, placed 30° into air blast or rotary atomizers into the air blast that produce an efficient spray particle with a mass medium diameter of 40 to 100 microns. Swath widths should not exceed 30 feet, and applications should not be made when winds exceed 5 mph.

Boom sprayers with a filtered rotary air compressor, either PTO or gas engine driven or an air pump capable of producing at least 12 psi are satisfactory. Use air pressure on chemical tanks and an accurate metering valve to assure a calibrated flow of the pesticide. Air should be regulated with relief valve and gauge for proper air and liquid mixture. Pneumatic type spray nozzles, as suggested by equipment manufacturer, should be used for spray particles with mass medium diameter of 30 to 100 microns. Applications should not be made when winds exceed 5 mph.

Repeat applications should be made as necessary unless otherwise specified.

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[a] Label of American Cyanamid Company, Princeton, New Jersey. EPA Registration Nos. 241-208AA and 241-110AA.

IMPORTANT

Undiluted spray droplets of MALATHION will permanently damage automobile paint. Cars should not be sprayed. If accidental exposure does occur, the car should be washed immediately. Consult your state experiment station or state extension service for proper timing of sprays.

This product is highly toxic to bees exposed to direct treatment. Protective information may be obtained from your Cooperative Agricultural Extension Service.

CROP	PESTS CONTROLLED	FLUID OUNCES PER ACRE	INTERVAL BETWEEN LAST APPLICATION AND HARVEST
Alfalfa	Alfalfa caterpillar Western yellow striped armyworm	8 – 12	Use lower rate when larvae are small. May be applied on day of harvest or grazing. Use higher rate when larvae are large or when alfalfa is thick. 5 days.
	Alfalfa weevil larvae	16	5 days. Apply when day temperatures are expected to exceed 65°F. and when 50 70% of leaves show feeding damage.
	Beet armyworm	8 – 16	Use lower rate when larvae are small. May be applied on day of harvest or grazing. Use higher rate when larvae are large or when alfalfa is thick. 5 days.
	Grasshoppers	8	May be applied on day of harvest or grazing.
	Do not apply to alfalfa in bloom. Do not apply to seed alfalfa.		
Beans (lima, green, snap, Navy, red kidney, wax, dry, black-eye)	Mexican Bean Beetle Leafhoppers Green Cloverworm Japanese Beetle Lygus Bug	8	1 day.
Blueberries	Blueberry Maggot	10	0 day.
Cherries	Cherry Fruit Fly	12 – 16	1 day. Apply by aircraft only. Use higher rate when foliage is heavy or infestation is severe. Make first application as soon as flies appear.
Cereal Crops, (barley, corn, oats, wheat) and grasses	Cereal leaf beetle	4 – 8	Barley, oats, wheat: 7 days of harvest or forage use. Corn: 5 days. Grasses: May be applied on day of harvest or grazing.
Clover, Pasture and Range Grass, Grass, Grass Hay, Nonagricultural Land (wastelands, roadsides, soil bank lands)	Grasshoppers	8	May be applied on day of harvest or grazing. Do not apply to clover in bloom.
Corn	Adult Corn Rootworm	4	5 days.
Cotton	Early Season Insects Thrips, Fleahoppers Leafhoppers	4 – 8	0 day.
	Boll Weevil	8 – 12	Early to midseason
		16	Diapause Weevil control - late season
	Grasshoppers	8	
	Lygus Bugs	8 – 12	
		16	Very heavy migrating populations.
Grain Crops (barley, corn, oats, rye, rice, grain sorghum and wheat)	Grasshoppers	8	7 days. Corn: 5 days of harvest or forage use.

Table 27. (Continued)

CROP	PESTS CONTROLLED	FLUID OUNCES PER ACRE	INTERVAL BETWEEN LAST APPLICATION AND HARVEST
Grain Sorghum	Sorghum Midge	8 – 12	Apply during the bloom stage. 7 days of harvest or forage use.
Rice – Grain Form (Louisiana, Texas)	Rice Stink Bug	8	7 days. Apply by aircraft only. Apply during early milk and dough stage of growing rice.
Safflower	Grasshoppers Lygus Bugs	8	3 days of harvesting seeds.
Soybeans	Mexican Bean Beetle Grasshoppers Japanese Beetle Green Cloverworm	8	7 days of harvest or forage use.
Sugar Beets	Grasshoppers Sugar Beet Root Maggot Adults	8	7 days if tops are to be used as feed.
Nonagricultural Lands	Beet Leafhopper (on wild host plants)	8	0 day.
Beef Cattle-Feed Lots and Holding Pens	Adult flies and Mosquitoes	6 – 8	0 day.

OTHER AGRICULTURAL USES

Alfalfa, Clover, Pasture and Range Grass, Grass, and Grass Hay, Grain Crops, Beans, Rice, Tomatoes and Nonagricultural Lands (wastelands, soil bank lands). Adult mosquitoes and flies. Apply MALATHION at the rate of 2 to 4 fluid ounces for control of adult mosquitoes and at 6 to 8 fluid ounces per acre for control of adult flies and mosquitoes. Repeat applications as necessary. On alfalfa, clover, pasture and range grass, grass, and grass hay, may be applied on day of harvest or grazing. Do not apply to alfalfa and clover in bloom. Do not use on seed alfalfa. On grain crops, make no application within 7 days of harvest or forage use; on corn, within 5 days of harvest or forage, on rice, within 7 days of harvest, on beans and tomatoes, within 1 day of harvest.

FOREST INSECTS

Apply with aircraft equipped for ultra low volume application. Make application when air is calm and temperature is below 68°F. Do not allow spray to contact ferns, hickory and maples as injury may result. Do not spray on elms under extreme heat, drought and disease conditions.

TREE	PESTS CONTROLLED	FLUID OUNCES PER ACRE	DIRECTIONS
Douglas Fir **True Fir** **Spruce**	Spruce Budworm	13	Apply when highest percentage of larvae are in the fifth instar.
Hemlock	Hemlock Looper	8	Apply when most larvae are in third and fourth instar.
Pines	European Pine Sawfly	10	Apply when larvae are in the first or second instar or before they reach ½ in length.
	Saratoga Spittlebug		Apply when 95% of the population has become adult.
Larch	Larch Casebearer	8	Apply in spring as soon as larvae break hibernation and begin feeding on new foliage

Before using CYTHION or MALATHION for the preparation of malathion insecticides, manufacturers should consult American Cyanamid Company for manufacturing and safe handling instructions.

The Sale of this product does not include a license under any patent owned by American Cyanamid Company.

The Tariff Commission report does not list the production and sales volumes of malathion individually. Malathion is included in a group consisting of seven other specified, and additional unspecified, acyclic organophosphate insecticides. The reported production volume for this composite group in 1972 was 65,181,000 lb of active ingredients.

Through a process of careful analysis of the use patterns of all organophosphate insecticides in this group supported by information from confidential trade sources, Midwest Research Institute[1] developed estimates on the volume of production of all major products in the group. *The estimated volume of production of malathion in 1972 is 24 million pounds of active ingredient*.

Imports - Imports of pesticides that are classified as "benzenoid chemicals" are reported in a U.S. Tariff Commission annual report covering FY72.[2] Malathion, an aliphatic chemical, is also covered in the report. According to the Tariff Commission, *153,769 lb of malathion were imported into the United States in 1972*.

Exports - Pesticide exports are reported by the Bureau of the Census[3] annually. Technical (unformulated) malathion is included in this report in Section 512.0659, a category including all technical organic phosphate insecticides except parathion and methyl parathion.

Formulations of malathion (and of all other organic phosphate insecticides) are included in Schedule B, Section 599.2035, entitled "Organic Phosphate Containing Pesticidal Preparations, Except Household and Industrial and Except Fly Sprays and Aerosols."

Total exports of organic phosphate insecticides in these two categories for 1972 were as follows:

Section 512.0659 (technical organic phosphate insecticides other than parathion and methyl parathion)	32,380,470 lb
Section 599.2035 (organic phosphate containing formulations)	15,898,884 lb

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[1] Midwest Research Institute/RvR Consultants, "Production, Distribution, Use, and Environmental Impact Potential of Selected Pesticides," Council on Environmental Quality, Contract No. EQC-311, (August 1, 1974).

[2] U.S. Tariff Commission, *Imports of Benzenoid Chemicals and Products*, TC Publication 601 (1973).

[3] U.S. Bureau of Census, *U.S. Exports*, Schedule B, *Commodity by Country*, Report FT 410.

To derive the 1972 export volume of malathion from these composite totals, Midwest Research Institute made a thorough analysis of these two pesticide export categories by unit dollar values and by countries of destination. In the next step, this information was matched against known crop protection problems and the pesticide trading patterns of the countries of destination. Additional information was obtained from confidential trade contacts, from the U.S. Agency for International Development (AID), as well as from other sources. Based on all data and information obtained from these sources, 1972 export volume of malathion is estimated to be 8.0 million pounds of active ingredient.

Domestic Supply - On the basis of the data presented in the preceding three sections, the domestic supply of malathion in the United States in 1972 was as follows:

	Quantity (Million lb AI)
U.S. production	24.0
Imports	0.2
Exports	8.0
Domestic supply	16.2

Formulations - Malathion is available to users in the United States in a variety of different formulations, including emulsifiable liquids, wettable powders, dusts, solutions, concentrates for low volume (LV) and ultra-low volume (ULV) applications, and manufacturing concentrates. The basic producer of malathion sells a substantial share of his production to formulator-customers in the form of technical or manufacturing concentrates. Formulators then prepare and sell formulations containing malathion under their own labels and brand names to end users, either directly or through wholesalers and/or retailers.

Frear (1972)[1/] lists the following pesticide products containing malathion as the only active ingredient:

1. 151 sprayable formulations (emulsifiable liquids, wettable powders, solutions, LV and ULV concentrates)
2. 38 dusts
3. 1 granular formulation
4. 11 manufacturing concentrates

[1/] Frear, D. E. H., Pesticide Handbook-Entoma, 24th Edition, College Science Publishers, State College, Pennsylvania (1972).

In addition to these products containing malathion as the only active ingredient, a number of liquid and dry formulations are offered that contain malathion in combination with other insecticides and/or fungicides.

The most widely used formulations of malathion are the ULV concentrate containing 95% of active ingredient (9.7 lb AI/gal), applied by ground or air equipment; and the 57% (5 lb AI/gal) emulsifiable liquid. These two formulations combined account for a large share of the total volume of use of malathion.

Use Patterns of Malathion in the United States

General - Agricultural and home and garden uses of malathion each accounted for almost one-third of the estimated domestic use of malathion in 1972, the balance consisting of industrial, commercial, and governmental uses.

Table 29 summarizes the estimated uses of malathion in the United States in 1972 by regions and major categories of use as determined in that study, with the exception that an adjustment has been made in the agricultural uses between the Southeastern and South Central states, based on information received very recently.

Agricultural Uses of Malathion - Surveys on the use of pesticides by farmers in the U.S. were conducted by the U.S. Department of Agriculture in 1964, 1966, and 1971 (Agricultural Economic Reports No. 131, published in 1968; No. 179, published in 1970; and No. 252, in press and soon to be published). Data on the farm uses of malathion in 1972 were obtained by RvR Consultants. Table 30 summarizes farm uses of malathion from these surveys. It appears that the level of use of malathion on agricultural crops, farm animals and for other farm uses has remained relatively constant during the period in question, even though the data from the two different sources are not directly comparable.

Table 31 presents a further breakdown of the farm uses of malathion in 1972 by regions and by major crops, based on estimates developed by RvR Consultants and on more recent studies.

Table 28. ESTIMATED USES OF MALATHION IN THE U.S. BY REGIONS AND CATEGORIES, 1972

Region	Category					
	Agriculture	Industrial/ commercial	Government agencies	Subtotal	Home and garden	Total
	(Thousands of pounds of active ingredient)					
Northeast[a/]	200	800	100	1,100		
North Central[b/]	1,000	1,200	300	2,500		
Southeast[c/]	1,050	800	1,200	3,050	Geographic distribution not known	
South Central[d/]	1,050	800	400	2,250		
Northwest[e/]	700	200	100	1,000		
Southwest[f/]	1,000	200	100	1,300		
Total	5,000	4,000	2,200	11,200	5,000	16,200

[a/] New England States, New York, New Jersey, Pennsylvania.

[b/] Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas.

[c/] Maryland, Delaware, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida.

[d/] Kentucky, Tennessee, Arkansas, Louisiana, Mississippi, Alabama, Oklahoma, Texas.

[e/] Montana, Idaho, Wyoming, Colorado, Utah, Washington, Oregon, Arkansas.

[f/] New Mexico, Nevada, Arizona, California, Hawaii.

Source: MRI/RvR estimates. See text.

Table 29. FARM USES OF MALATHION IN THE U.S. IN 1964, 1966, 1971 AND 1972

Source	1972 RvR[a]	1971 USDA[b]	1966 USDA	1964 USDA
	(Thousands of pounds of active ingredient)			
Crops	4,100	2,711	4,286	4,066
Livestock	700	652	735	602
Other farm uses	200	239	197	100
Total farm uses	5,000	3,602	5,218	4,768

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a/ RvR estimates. See text.

b/ U.S. Department of Agriculture Reports on quantities of pesticides used by farmers, in 1964 (Agricultural Economic Report No. 131, published 1968); in 1966 (Agricultural Economic Report No. 179, published 1970); in 1971 (Agricultural Economic Report No. 252, in press).

Table 30.* ESTIMATED FARM USES OF MALATHION IN THE U.S. BY REGIONS AND MAJOR CROPS AND OTHER USES, 1972

	Crop							
Region	Cotton	Other field crops	Forage, crops, rangeland	Fruit crops	Vegetables, etc.	Livestock	Other farm uses	Total, all farm uses
	(Thousands of pounds of active ingredient)							
Northeast[a]	--	Negl.	50	50	50	50	Negl.	200
Southeast[b]	150	150	50	300	200	150	50	1,050
North Central[c]	Negl.	200	350	200	100	150	Negl.	1,000
South Central[d]	650	50	50	50	50	150	50	1,050
Northwest[e]	--	150	350	50	Negl.	100	50	700
Southwest[f]	100	100	150	300	200	100	50	1,000
Total, all regions	900	650	1,000	950	600	700	200	5,000

***RvR estimates. See text.**

a/ New England States, New York, New Jersey, Pennsylvania.

b/ Maryland, Delaware, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida.

c/ Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas.

d/ Kentucky, Tennessee, Arkansas, Louisiana, Mississippi, Alabama, Oklahoma, Texas.

e/ Montana, Idaho, Wyoming, Colorado, Utah, Washington, Oregon, Arkansas.

f/ New Mexico, Nevada, Arizona, California, Hawaii.

The following information sources were used in arriving at these estimates:

1. The three USDA surveys of pesticide uses by farmers mentioned above.
2. The annual USDA publication "Pesticide Review" (Agricultural Stabilization and Conservation Service).
3. Results of a survey of the Federal/State Cooperative Extension Services in all 50 states and in Puerto Rico conducted by RvR Consultants in 1973.
4. Analyses of state pesticide use recommendations.
5. Local and regional estimates on pesticide use volumes obtained from State Research and Extension personnel in personal communications.
6. Pesticide use reports from the States of Arizona, California, Illinois, Indiana, Michigan, Minnesota, and Wisconsin.
7. Data on pesticide uses supplied by the EPA Community Pesticide Studies Projects in Arizona, Hawaii, Idaho, Mississippi, South Carolina, Texas, and Utah.
8. Estimates and information obtained from basic producers of malathion and other pesticides, and from pesticide trade sources.
9. Pesticide use surveys conducted recently by Wallaces' Farmer, Des Moines, Iowa; Prairie Farmer, Chicago, Illinois; and Wisconsin Agriculturist, Madison, Wisconsin.
10. "Agricultural Statistics," an annual publication of the U.S. Department of Agriculture.

Data from all of these diverse sources were carefully analyzed, correlated, cross-checked and cross-validated.

Farm uses of malathion by regions - It is estimated that about 5.0 million pounds of malathion AI were used in agriculture in the U.S. in 1972 (Table 31). The total quantity of malathion used by farmers was distributed fairly evenly over all geographic regions, except the Northeastern states where, it is estimated, only about 200,000 lb of malathion were used in 1972. The Northwestern states used an estimated 700,000 lb, whereas the remaining four regions each used about 1.0 million pounds.

In all regions malathion was used on a variety of field, forage, fruit, and vegetable crops; on livestock; and for the control of insects in farm buildings and premises, including protection of stored grains, feeds, other commodities, and for similar purposes.

Farm uses of malathion by crops - Analyzing the agricultural uses of malathion by commodities (Table 31), it appears that no single crop predominates. According to Midwest Research Institute estimates, the use of malathion on forage crops and rangeland (against grasshoppers and other insect pests affecting these crops) accounted for about 1.0 million pounds AI, that is about 20% of all farm uses. About 350,000 lb each were used for these purposes in the North Central and Northwestern states; about 150,000 lb in the Southwest; the balance in the Northeastern, Southeastern, and South Central states (50,000 lb each).

Uses on fruit crops (including citrus fruits, deciduous tree fruits and nuts, and all other fruits) accounted for another 20% of the total farm use of malathion. About 300,000 lb of malathion each were used in the Southeastern and Southwestern states, followed by the North Central (200,000 lb), and the Northeastern, North Central and South Central states (about 50,000 lb each).

Approximately 900,000 lb of malathion AI were used on cotton in 1972. The largest share of this quantity was used in the South Central states, in the diapause boll weevil control program in the high and rolling plains of northern Texas. Smaller amounts of malathion were used on cotton in the Southeastern and Southwestern states.

Approximately 650,000 lb of malathion were used on field crops other than cotton (including corn and other grains, soybeans, peanuts and tobacco), and about 600,000 lb on vegetable crops. In both categories, the quantities used were distributed fairly evenly over all regions of the country.

An estimated 700,000 lb of malathion were used on livestock in 1972, again distributed fairly evenly over all geographic regions.

Finally, an estimated 200,000 lb were used for other purposes on farms, including insect control in and around farm homes, other farm buildings such as barns, milk rooms, feed processing areas, feedlots, poultry houses, grain bins; for the protection of stored grains and other farm commodities; for mosquito control in and around farm ponds; and for similar uses.

Industrial, Commercial, and Institutional Uses of Malathion - An estimated 4.0 million pounds of malathion were used in 1972 by industrial, commercial, and institutional organizations.

Malathion is used in this field against insects in food and beverage processing, packaging and distributing establishments; in dairies; warehouses; and food-handling and -serving places such as bars, restaurants, grocery stores, and meat markets.

Institutions such as hospitals, nursing homes, schools, museums, and many others use malathion for the control of indoor as well as outdoor pests. Organizations responsible for outdoor gatherings of people (drive-in theaters, recreational areas, picnic grounds, etc.) use malathion against outdoor nuisance insects such as mosquitoes and flies.

In addition, malathion is used for the protection of stored products in warehouses, bins, shipholds and many other containers.

In many of the insect control situations described in the preceding paragraphs, malathion is applied by professional pest control operators. However, sizable quantities of malathion are also applied by commercial, industrial and institutional organizations and their employees themselves, since, due to its relatively low mammalian toxicity, the handling of malathion does not require extraordinary safety equipment and precautionary measures.

The estimated geographical distribution of the use of malathion for industrial, commercial and institutional insect control purposes is outlined in Table 29. According to these estimates, the largest quantity of malathion in this category is used in the North Central region. primarily due to the extensive storage of food and feed grains in this area.

Governmental Agencies' Uses of Malathion - An estimated 2.2 million pounds of malathion AI were used by Federal, state, regional, county, local, and other governmental agencies in 1972. These estimates were developed by Midwest Research Institute. Data sources used included several nationwide surveys, expert consultants, and the Federal Working Group on Pest Management.

Governmental agencies use malathion primarily for regional or areawide insect control purposes, such as mosquito control; control of insects in quarantine programs (e.g., fruit flies, cereal leaf beetle); areawide insect eradication or suppression programs (cotton boll weevil, grasshoppers); control of nuisance insects in public parks, recreation areas and picnic grounds. Malathion is also used for the protection of military and other governmental personnel and supplies from insects and insect damage.

It is estimated that about 1.2 million pounds of malathion were used by governmental agencies in the Southeastern states in 1972, which is more than one-half of the total quantity (2.2 million pounds) used in this category nationally. Malathion use by government agencies in the South Central states is estimated at 400,000 lb; in the North Central states, 300,000 lb; while the Northeastern, Northwestern and Southwestern states each used about 100,000 lb of malathion in governmental programs.

Home and Garden Uses of Malathion - It is estimated that about 5.0 million pounds of malathion AI were used by home owners and amateur gardeners in the U.S. in 1972. The use patterns of malathion in this area were not investigated in the MRI/RvR study on 25 selected pesticides. No other published quantitative data is known to be available on nationwide home and garden pesticide uses.

Most probably, the use of malathion in and around homes and gardens is relatively heavier in the Southern states because of the warmer climate, longer vegetation season and greater abundance of home and garden insects in these areas. However, malathion is also widely used in the Northern states for home and garden insect control purposes.

Nearly all retail outlets for home and garden pesticides throughout the entire U.S. carry one or more formulations containing malathion.

Malathion Uses in California - The State keeps detailed records of pesticide uses by crops and commodities. The records are quarterly and summarized annually. Table 32 summarizes major crop and other uses of malathion in California for 1970 to 1973.

In California, malathion is not subject to the special restrictions and reporting requirements imposed upon the sale and use of pesticides designated as "injurious materials." For this reason, the percentage of all malathion uses reported to the State Department of Agriculture and included in its statistics is probably not as high as in the case of restricted pesticides. However, the State Department of Agriculture and others familiar with pesticide uses in California believe that the Department's statistics do include a high percentage of the actual uses of nonrestricted pesticides.

Table 31.* MALATHION USES IN CALIFORNIA BY MAJOR CROPS AND OTHER USES, 1970-1973

Crop	Year 1973	1972	1971	1970
	(thousands of pounds of active ingredient)			
Citrus (oranges, lemons, grapefruit)	344	150	740	119
Alfalfa, clover	148	169	186	137
Cotton	42	60	24	19
Safflower	19	29	39	22
Sugar beets	17	20	10	16
Beans	32	49	33	41
Melons (including watermelons)	14	83	41	12
Lettuce	135	60	94	112
Other farm uses (including commercial ornamentals)	103	121	70	89
Vector control	79	62	3	11
Noncrop uses (including residential, industrial, structural pest control; uses by governmental agencies)	89	119	222	522
Totals, all uses	1,022	922	1,462	1,100

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*California Department of Agriculture, Pesticide use reports for 1970, 1971, 1972 and 1973.

According to these state reports (Table 32), the use of malathion in California for all purposes varied between 922,000 lb in 1972 and 1,462,000 lb in 1971. There were even greater variations in the use of malathion on individual crops between 1970 and 1973. For instance, only 119,000 lb of malathion were used on citrus in 1970, compared to 740,000 lb in 1971. The quantities of malathion used on melons and on lettuce, and for vector control also showed great variations between years.

In 1970, 522,000 lb of malathion were used for insect control purposes other than farm uses and vector control. Of this quantity, 356,838 lb are recorded as used on 224,304 acres not further identified. In all probability, these 356,838 lb were used primarily or entirely on farm crops. This would bring the remaining quantity applied for noncrop uses more in line with the quantities used in this category in the other 3 years.

Tables 33 and 34 present the malathion uses in California by crops or other uses, number of applications, pounds of active ingredient, and number of acres treated for 1972 and 1973, the two most recent years for which such data are available. In both years, malathion was used in California for about 120 to 130 different insect control purposes, including use on over 100 different crops.

The California Department of Agriculture's malathion use statistics cover primarily malathion uses by farmers and by governmental agencies. They probably include only a smaller percentage of malathion uses by industrial, commercial and institutional agencies, and in the home and garden field.

At the present time, no other state records or publishes pesticide use data in comparable detail. Limitations of time and resources available did not permit development of estimates on the uses of malathion by states, crops, and other uses, beyond the detail provided in Tables 29, 30, and 31.

Table 32. USE OF MALATHION IN CALIFORNIA IN 1972, BY CROPS, APPLICATIONS, QUANTITIES, AND ACRES TREATED

Commodity	Applications[a]	Lb	Acre[b]
Alfalfa	928	136,996.29	83,766.80
Alfalfa for seed	122	19,521.00	16,778.00
Almond	6	1,838.96	173.50
Apple	1	2.50	4.00
Apricot	1	9.60	24.00
Artichoke	6	261.28	204.00
Asparagus	38	4,862.47	4,145.00
Barley	1	37.00	70.00
Barn	2	30.26	1.50
Beans, dry edible	354	47,841.68	27,554.00
Beans, green or forage	12	778.66	549.00
P - Beans for seed[b]	3	3.93	7,874,400
Beet	8	532.46	318.00
Berries	3	187.85	109.00
Birdsfoot, trefoil	1	62.48	40.00
Boysenberry	22	588.43	289.50
Broccoli	22	913.79	700.05
Brussel sprout	1	6.15	6.00
Bushberries	7	179.00	119.00
Cabbage	27	1,092.18	653.00
Cantaloupe	16	72,507.90	2,488.00
Carrot	20	5,322.58	539.50
Cattle lot	1	7.23	10.00
Cauliflower	23	718.20	616.00
Celery	458	10,433.45	7,277.13
Cherries, sweet	6	181.22	66.00
Chinese cabbage	2	20.24	18.00
Chives	14	474.50	146.00
Citrus	106	12,643.27	2,267.09
City agency		3,330.53	
Clover	87	11,878.08	9,154.00
Clover for seed	7	572.39	375.00
Cole crops for seed	1	1.02	1.00
Conifer	1	19.43	35.00
Corn, field	64	1,013.03	960.00
Corn, sweet	4	750.81	109.00
Cotton	307	60,454.61	57,353.00
County Agricultural Commissioner		176.91	
County or city parks		2,020.24	
County road		128.83	
Cucumber or pickle	95	3,737.92	2,535.50
Date	171	5,645.25	1,737.00
Deciduous ornamental trees	4	150.11	94.10
Endive	2	18.67	9.00
Federal agency		617.42	
Fallow (open ground)	1	54.09	37.00
Flood control		549.95	
Flowers	20	239.03	115.99
Foliage	2	148.51	85.00
Garlic	11	856.57	606.00
Granary	2	0.16	0.02
Grapefruit	26	1,582.89	322.50
Grape	44	6,404.10	1,975.50
Greenhouse	4	144.97	47.00
Hops	1	80.00	80.00
Industrial areas	1	8.20	16.00
Lemon	222	12,864.90	3,782.33
Lettuce, head	1,197	59,632.29	37,854.97
Lettuce, leaf	8	126.23	86.75
Lime	9	28.26	6.15
Livestock	1	20.95	20.00
Melons	30	2,532.14	2,265.00
Nectarine	6	132.00	48.00
Nonagricultural areas	9	244.07	389.70
Nursery stock	15	346.54	178.80
Olive	7	175.68	85.00
Onion, dry	111	7,110.44	4,030.50
Orange	1,398	135,676.94	31,764.68
Ornamentals	79	724.18	442.76
Ornamental bedding plants	1	0.04	0.60
Other agencies		10,762.59	
Pasture, rangeland	109	19,095.83	30,537.00
Peach	10	633.89	110.85
Pea	8	102.20	77.00
Pecan	1	3.84	3.00
Pepper, bell	2	43.18	41.00
Plum	4	43.04	63.00

Table 37. (Continued)

Commodity	Applications	Lb	Acres b/
Potato	6	419.46	435.00
Prune	1	1.92	12.00
Pumpkin	25	940.06	607.00
Radish	1	25.14	12.00
Raspberry	1	88.23	20.00
Residential control		31,985.56	
Residential control	2	18.46	6.00
Residential control		30.00	
Rice	2	67.19	62.50
Roses	3	7,633.46	64.00
Ryegrass for seed	2	434.95	714.00
Safflower	181	29,194.07	30,748.50
School district		646.46	
Sesame, seed	1	32.83	32.00
Sorghum	8	757.18	730.00
Spinach	14	319.41	218.00
Squash, summer	27	1,255.35	778.50
Squash, winter	8	209.31	131.00
State highway		242.77	
Strawberry	39	2,661.19	1,418.00
Structural control		77,733.93	
Subtropical fruits	1	16.35	5.00
Sudangrass	1	14.46	10.00
Sugar beet	193	19,599.05	13,709.50
Tangelo	3	168.00	49.00
Tangerine	2	511.25	203.30
Tomato	51	6,982.39	3,427.00
Turf	2	171.64	220.50
University of California		104.02	
Vector control		61,605.40	
Walnut	33	767.53	388.75
T - Walnut	1	0.50	1
Water areas	9	111.27	90.00
Water resources		3.90	
Watermelon	26	8,331.00	1,553.00
Wheat	2	20.82	36.00
Total	6,938	922,034.02	392,048.22

Footnotes

a/ Only agricultural applications are tabulated in this column.

b/ When the commodity listed is prefixed by P or T, the amount listed in the respective acreage column is not acreage but one of the following, and is not included in total acreage.

P = Pounds
T = Number of trees

Source: State of California, Department of Agriculture, "Pesticide Use Report" (1972).

Table 43. USE OF MALATHION IN CALIFORNIA IN 1973, BY CROPS, APPLICATIONS, QUANTITIES, AND ACRES TREATED

Commodity	Applications[a]	Lb	Acres[b]
Alfalfa	1,030	116,708.81	95,695.50
Alfalfa for seed	88	17,953.22	12,359.00
Almond	3	1,040.74	706.00
Apple	6	272.00	276.00
Apricot	2	15.77	44.00
Artichoke	5	3,405.36	121.00
Asparagus	47	6,526.50	3,708.00
Avocado	2	8.80	16.00
Barley	7	280.07	251.00
Barn	1	0.10	1.00
Beans, dry edible	315	31,950.92	24,089.00
Beans, green or forage	2	24.17	18.00
Beans for seed	1	79.96	48.00
P - Beans for seed[b]	5	3.53	288,200
Beet	33	1,986.31	1,974.00
Berries	5	144.66	80.00
Boysenberry	28	755.71	373.00
Broccoli	24	808.16	451.83
Brussel sprout	4	11.20	9.00
Cabbage	70	3,926.03	2,758.67
Cantaloupe	31	6,203.43	4,842.00
Carrot	29	1,622.69	1,102.00
Cattle, beef	1	0.43	150.00
L - Cattle, beef	15	63.84	1,896
Cattle lot	1	1.00	2.00
U - Cattle lot	1	1.76	1
Cauliflower	19	147.50	90.50
Celery	423	10,944.12	7,273.75
Cherries, sweet	2	50.50	80.00
Chinese cabbage	3	71.00	47.00
Chives	4	59.49	58.00
Citrus	44	3,597.23	999.00
City agency		2,161.02	
Clover	81	13,361.61	9,050.00
Clover for seed	5	428.76	426.00
Collard	1	1.00	2.00
Conifer	1	701.78	120.00
Corn, field	45	763.21	643.00
Corn, sweet	2	11.18	43.00
Cotton	272	41,878.13	37,495.50
County Agricultural Commissioner		226.38	
County or city parks		2,056.10	
Crenshaw melon	1	40.84	40.00
Cucumber or pickle	103	3,062.03	2,028.61
Date	200	5,071.00	1,643.50
Deciduous ornamental trees	1	2.05	2.00
T - Deciduous ornamental trees	1	2.56	6
Eggplant	5	14.22	13.00
Evergreen trees and shrubs	2	13.75	11.00
Federal agency		751.35	
Fallow (open ground)	4	59.57	45.25
Fig	21	17,798.00	4,759.00
Flowers	77	643.67	240.80
U - Flowers	3	5.60	19,091
Foliage	5	37.43	27.75
Garlic	3	295.73	171.00
U - Granary	6	79.19	8
Grapefruit	27	37,703.98	373.00
Grape	99	3,571.74	2,717.50
Greenhouse	2	71.94	25.00
U - Greenhouse	1	0.16	1
Honeydew melon	1	120.00	80.00
Hops	4	368.00	368.00
Industrial areas	8	137.94	321.00
U - Industrial areas	9	76.13	209
Lemon	146	66,841.55	2,923.50
Lettuce, head	1,388	134,060.21	72,972.53
Lettuce, leaf	21	617.88	340.00
Lime	1	0.96	0.50
T - Lime	5	14.59	494
L - Livestock	2	4.85	1,585
Melons	53	5,685.15	4,676.75
U - Miscellaneous	1	1.08	9
Mushroom	9	107.12	169.12
U - Mushroom	3	1.08	81,000
Mushroom house	3	1.40	2.53
U - Mushroom house	7	4.50	7

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Commodity	Applications	Lb	Acres[b/]
Mustard green	2	2.08	2.50
Nectarine	2	15.13	12.00
Nonagricultural areas	7	135.22	151.03
Nursery stock	8	411.04	170.38
U - Nursery stock	2	3.07	101
Oats	6	86.10	347.00
Olallieberry	1	4.38	4.00
Olive	4	181.87	65.00
Onion, dry	143	9,597.66	5,766.00
Onion, green, spring, shallot	15	19.98	21.99
Orange	1,327	236,188.84	34,036.51
T - Orange	4	15.49	341
Ornamentals	34	196.16	50.50
T - Ornamentals	1	8.30	10
U - Ornamentals	3	24.90	37,500
Ornamental bedding plants	7	53.25	12.73
Other agencies		21,092.68	
Pasture, rangeland	8	1,458.82	2,321.00
Peach	10	628.88	119.50
T - Peach	2	6.00	33
Pear	2	4.96	4.00
Pea	180	572.60	534.70
Pepper, bell	5	17.87	13.85
Plum	4	58.93	58.00
Pomegranate	1	350.89	80.00
Potato	24	2,511.41	1,682.00
U - Poultry house	3	12.00	43
Prune	4	83.90	267.00
Pumpkin	15	302.31	266.00
Raisin	1	232.00	145.00
Raspberry	2	38.31	14.00
Residential control		30,583.70	
Residential control	2	2.75	3.50
T - Residential control	1	0.75	1
U - Residential control	1	6.60	44
Rice	3	326.71	386.00
Roses	2	31.40	21.00
Safflower	102	19,057.45	20,218.00
School district		323.54	
L - Sheep and lambs	1	11.02	2,500
Sorghum	22	1,376.88	1,165.00
Spinach	26	202.45	191.25
Squash, summer	41	1,414.37	774.50
Squash, winter	14	149.85	111.50
State highway		130.33	
Strawberry	112	4,662.29	2,714.00
Structural control		31,293.76	
U - Structural control	11	46.50	338
Sugar beet	121	16,855.97	11,079.00
Sweet potato	12	711.98	266.00
L - Swine	1	0.10	9
Tangelo	2	37.49	12.00
Tangerine	2	80.79	90.00
Tomato	78	8,866.40	2,266.39
Turf	1	27.41	100.00
Turnip	2	13.56	12.50
University of California		135.66	
Vector control		79,351.76	
Vector control	1	70.53	100.00
Walnut	55	1,307.84	718.98
T - Walnut	5	8.55	20
Water areas	3	135.10	270.00
Water resources		1.25	
Watercress	8	66.37	39.00
Watermelon	23	2,409.20	1,967.00
Wheat	5	175.92	204.00
Zucchini	1	2.50	2.00
Total	7,365	1,021,715.49	388,205.40

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a/ Only agricultural applications are tabulated in this column.

b/ When the commodity listed is prefixed by L, P, U, or T, the amount listed in the respective acreage column is not acreage but one of the following, and is not included in total acreage:

L = Number of livestock
P = Pounds
U = Miscellaneous units
T = Number of trees

Source: State of California, Department of Agriculture, "Pesticide Use Report" (1973).

PART III. MINIECONOMIC REVIEW

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This section contains a general assessment of the efficacy and cost effectiveness of malathion. Data on the production of malathion in the United States as well as an analysis of its use patterns at the regional level and by major crop, were conducted as part of the Scientific Review (Part II) of the report. This section summarizes rather than interprets scientific data reviewed.

Introduction

The efficacy and cost effectiveness of a specific pesticide should be measurable in terms of the increased yield or improved quality of a treated crop which in turn results in a greater income or lower cost than would be achieved if the pesticide has not been used. Thus, one should be able to pick an isolated test plot of a selected crop, treat it with a pesticide, and compare its yield with that of a nearby untreated test plot. The difference in yield should be the increase due to the use of the pesticide. The increased income (i.e., the yield multiplied by the selling price of the commodity) less the additional costs (i.e., the pesticide, its application and the harvesting of the increased yield) is the economic benefit due to the use of the pesticide.

Unfortunately, this method has many limitations. The data derived is incomplete and should be looked on with caution. A review of available literature and EPA registration files revealed that experimental tests comparing crops treated with specific pesticides to the same crop without treatment are conducted by many of the state agricultural experimental stations. Only a few of these, however, have attempted to measure increased yield and most of this effort has been directed toward just a few crops such as cotton, potatoes, alfalfa and selected fruits. Most other tests on crops measure the amount of reduction in pest levels which cannot be directly related to yield.

Even the test plot yield data are marginally reliable, since these tests are conducted under actual field conditions that may never be duplicated again and may not be representative of general field use. Thus, yield is affected by rainfall, fertilizer use, severe weather conditions, soil type, region of the country, pesticide infestation levels and the rate, frequency and method of pesticide application.

Because of these factors, yield tests at different locations and in different years will show a wide variance ranging from a yield decline to significant increases. For example, in a year of heavy pest infestation, frequent pesticidal use can result in a high yield increase because the crop from the untreated test plot is practically destroyed. Conversely, in a year of light (or insignificant) infestation, the yield increase will be slight (or undetectable).

Thus, the use of test plot yield data is at best qualitative and is used for order-of-magnitude economic cost and benefit determination.

The use of market price to estimate the value received by the producer also has its limitations. If the use of the pesticide increases the yield of a crop and the national production is increased, then the market price should decline. According to J. C. Headley and J. N. Lewis (1967),[1/] a 1% increase in quantity marketed has at times resulted in a greater than 1% decrease in price. Thus, the marginal revenue from the increased yield would be a better measure of value received.

A third limitation to the quantification of the economic costs and benefits is the limited availability of data on the quantities of the pesticide used by crop or pest, the acres treated, and the number of applications. In most cases the amount of malathion used on each crop or each pest is not available.

As a result of these limitations an overall economic benefit by crop or pest cannot be determined. This report presents a range of the potential economic benefits derived from the use of malathion to control a specific pest on a specific crop. This economic benefit or loss is measured in dollars per acre for the highest and lowest yield increase developed from experimental tests conducted by the pesticide producers and the state agricultural experimental stations. The high and low yield increases are multiplied by the price of the crop and reduced by the cost of the malathion applied to generate the range of economic benefits in dollars per acre.

Efficacy and yield changes due to the use of malathion have been reported for a wide variety of pest-crop combinations. These include the boll weevil on cotton; the greenbug and sorghum midge on sorghum; the potato leafhopper on soybeans; the sugar beet maggot on sugar beets; the corn rootworm on corn; the alfalfa weevil on alfalfa; grasshoppers on rangeland; the cherry fruit fly on cherries; the tarnished plant bug

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[1/] Headley, J. C., and J. N. Lewis, The Pesticide Problem: An Economic Approach to Public Policy, Resources for the Future, Inc., pp. 39-40 (1967).

on strawberries; the mexican bean beetle on beans; the pea aphid on peas; the potato aphid and leafhopper on potatoes; and the horn fly, stable fly and other small insects on cattle.

Efficacy and yield changes have been evaluated due to the use of malathion based on 1972 cost data. The results of these evaluations are summarized in the following paragraphs.

Cotton

The use of malathion on cotton is primarily for control of the boll weevil as it enters diapause. It is also recommended in some areas for the control of thrips, two spotted spider mites and grasshoppers.

Efficacy Against Pest Infestation - The three major insects that attack cotton are the tobacco budworm, the bollworm and the boll weevil. Malathion is relatively ineffective against the budworm and bollworm and is not recommended in some states for this use against those insects. In a test of several organophosphate insecticides, Plapp (1971)[1/] found that malathion was not highly toxic to either the budworm or bollworm. Similar results were obtained by Cowan and Davis (1968)[2/] who concluded that malathion did not control bollworms or tobacco budworms.

Malathion has been found to be effective on the boll weevil as it enters diapause. Lloyd et al. (1972)[3/] concluded that ULV formulations of malathion gave effective control of boll weevils during tests conducted in 1966 and 1967 in Carroll County and State College, Mississippi. Applications of 0.25 to 0.50 lb of malathion every 4 to 5 days provided effective control. Cowan and Davis (1968) also concluded that ULV applications of malathion at 0.4 to 0.8 lb/acre gave good control of the boll weevil. These tests were conducted at Waco, Texas, in 1967.

[1/] Plapp, F. W., Jr., "Insect Resistence in Heliothis: Tolerance in Larvae of H. virescens as Compared with H. zea to Organophosphate Insecticides," J. Econ. Entomol., 64:999-1002 (1971).

[2/] Cowan, C. B., Jr., and J. W. Davis, "Field Tests with Conventional Low Volume and Ultra-Low-Volume Sprays for Control of the Boll Weevil, Bollworm and Tobacco Budworm on Cotton in 1967," J. Econ. Entomol., 61:1115-1116 (1968).

[3/] Lloyd, E. P., J. P. McCoy, W. P. Scott, E. C. Burt, D. B. Smith, and F. C. Tingle, "In-Season Control of the Boll Weevil with Ultra-Low-Volume Sprays of Azinphosmethyl or Malathion," J. Econ. Entomol., 65:1153-1156 (1972).

There appears to be little change in the efficacy of malathion to the boll weevil. Namec and Adkisson (1968 to 1972)[1] have conducted toxicity tests of insecticides to the boll weevil. Data since 1968 are shown below.

Table 34. MALATHION EFFICACY TESTING RESULT ON BOLL WEEVILS

Insecticide	Lb/acre	% kill (48 hr)	Year
Malathion	1.0	78	1968
Malathion	1.0	92	1969
Malathion	1.0	82	1970
Malathion	0.5	100	1971
Malathion	1.0	100	1971

Cantu and Wolfenbarger (1969 to 1972)[2] have conducted tests on the toxicity of two spotted spider mites to malathion. The results as shown below do not indicate any reduction in efficacy over a 4-year period.

Table 35. MALATHION EFFICACY TESTING RESULTS ON SPIDER MITES

Insecticide	% concentration (ppm)	% kill after 72 hr (foliar spray)	Year
Malathion	0.25	90	1969
Malathion	0.01	27	1969
Malathion	0.25	88	1970
Malathion	0.01	24	1970
Malathion	0.25	86	1971
Malathion	0.01	20	1971
Malathion	0.25	88	1972
Malathion	0.01	20	1972

On the basis of these results it appears that there is no reduction in the efficacy when malathion is used to control the boll weevil and two spotted spider mites.

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[1] Nemec, S. J., and P. L. Adkisson, "Laboratory Tests of Insecticides for Bollworm, Tobacco Budworm and Boll Weevil Control," Investigations of Chemicals for Control of Cotton Insects in Texas (1968-1972).

[2] Cantu, E., and D. A. Wolfenbarger, "Effectiveness of Experimental Insecticides for Control of the Tobacco Budworm, Boll Weevil, Fall Armyworm, and Two Spotted Spider Mites," Investigations of Chemicals for Control of Cotton Insects in Texas (1969-1972).

Cost Effectiveness of Pest Control - There have been a limited number of studies on the change in cotton yield due only to the use of malathion. It is most often used in mixtures with methyl parathion to control the budworm and the boll weevil.

Yield increases from tests comparing malathion-treated cotton to untreated test plots varied widely depending upon the number of applications and the degree of pest infestation. Data were only available from seven tests conducted in Mississippi and Texas.

The wide range in yield increase is often due to the variance in the rate of pest infestations. Pfrimmer et al. (1971)[1] reported that during tests in 1969 a field that normally produced 1,500 to 2,000 lb of seed cotton per acre produced only one-tenth of the normal yield without any insecticidal treatment.

The 1972 price received by farmers for cotton was 24.0¢/lb for lint. Additional income from cottonseed at 4.2¢/lb and government price supports of 12.5¢/lb brought the total income to 40.7¢/lb of cotton (Agricultural Statistics, 1973[2]). Malathion costs averaged $1.20/lb (Bost 1974[3]); application costs are $1.25 per treatment. Economic benefits would range from $5.95 to $683.96.

The range of yield changes from all of the data reviewed varied from a small gain of 20 lb/acre to a substantial increase of 1,730 lb/acre when compared to untreated test plots. The economic benefit after subtracting the cost of the malathion ranged from $6.70/acre to $700.21/acre.

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[1] Pfrimmer, T. R., R. E. Furr, and E. A. Stadelbocher, "Materials for Control of Boll Weevils, Bollworms, and Tobacco Budworms on Cotton at Stoneville, Mississippi," *J. Econ. Entomol.*, 64:475-478 (1971).

[2] *Agricultural Statistics 1973*, U.S. Department of Agriculture (1973).

[3] Bost, W. M., Director, Cooperative Extension Service, Mississippi State, Mississippi, personal letter to D. F. Hahlen (1974).

The results of the yield tests are tabulated below.

Table 36. YIELD AND BENEFIT ANALYSIS RESULTS OF MALATHION ON SELECTED COTTON PESTS

Date	Application		Yield increase (lb/acre)	Additional income ($/acre at 40.7¢/lb)	Application Cost at $1.20/lb plus treatment cost at $1.25/ effort	Economic benefit ($)	Source
	Rate (lb AI/acre)	No.					
1956	1.0	5	205	83.45	12.25	71.20	a/
1956	1.0	9	458	186.41	22.05	164.36	a/
1958	0.5	7	714	290.60	12.95	277.65	a/
1967	0.25	13	1,730	704.11	20.15	683.96	a/
1967	0.5	13	1,170	476.19	24.05	452.14	a/
1967	0.4	3	20	8.14	2.19	5.95	b/
1967	0.8	3	40	16.28	3.63	12.65	b/

a/ Bost, *op. cit.* (1974).
b/ Cowan et al., *op. cit.* (1968).

Sorghum

Malathion is registered for control of the sorghum midge, greenbug and grasshoppers on sorghum. Of these, the greenbug and sorghum midge are the two most important insects affecting yield.

Efficacy Against Greenbug Infestation - Although there are numerous insects treated with malathion, perhaps the greenbug on sorghum is the most important. Prior to 1968, the greenbug had been found mostly in small grains such as wheat, barley and oats. However, in 1968 a new biotype emerged and began infesting sorghum. Ward et al. (1970)[1] noted that in 1968, 7.3 million acres became infested resulting in a production loss estimated at $20 million. Cate et al. (1973)[2] reported that the Grain Sorghum Producers Board estimated that $14 million was spent for control of grain sorghum pests in 1970 compared with a total of only $100,000 spent prior to 1968. Malathion has been found to be an effective insecticide against the greenbug.

Since the development of the biotype C greenbug infestation on sorghum is recent, the efficacy data does not indicate any resistance to malathion. Cate et al. (1973), in tests on sorghum in 1970, showed that malathion applied at 1.0 lb/acre gave a 97% seasonal control. Harvey and Hackerott (1970)[1] detailed test results indicating 92% control 10 days after treatment.

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[1] Ward, C. R., E. W. Huddleston, D. Ashdown, J. C. Owens, and K. L. Polk, "Greenbug Control on Grain Sorghum and the Effects of Tested Insecticides on Other Insects," *J. Econ. Entomol.*, 63:1929-1934 (1970).

[2] Cate, J. R., Jr., D. G. Bottrell, and G. L. Teets, "Management of the Greenbug on Grain Sorghum. I. Testing Foliar Treatments of Insecticides Against Greenbugs and Corn Leaf Aphids," *J. Econ. Entomol.*, 66:945-951 (1973).

Cost Effectiveness of Greenbug Control - The results of several tests in Texas and Kansas show that yield increases varied from 243 lb/acre to 1,479 lb/acre when malathion-treated sorghum was compared to an untreated test plot. The price of sorghum averaged \$2.25/Cwt in 1972 (*Agricultural Statistics*, 1973) and the cost of malathion was \$1.20/lb (Bost, 1974). At these prices and costs, the economic benefits would range from \$3.09/acre to \$30.83/acre for the use of malathion to control the greenbug, while application costs are \$1.25 per treatment. These tests are summarized as follows:

Table 37. YIELD AND BENEFIT ANALYSIS RESULTS OF MALATHION ON SORGHUM GREENBUGS

Date	Application (lb AI/acre)	Yield increase (lb/acre)	Additional income at \$2.25/Cst (\$/acre)	Application cost at \$1.20/lb plus treatment cost at \$125/effort	Economic benefit (\$)	Source
1969	1.0 - milk stage	1,479	33.28	2.45	30.83	a/
1969	1.0 - pre-boot stage	270	6.08	2.45	3.63	a/
1968	1.25	293	6.59	2.75	3.84	b/
1969	0.94	243	5.47	2.38	3.09	c/
1970	0.25	533	11.99	1.55	10.44	c/
1970	1.0	666	14.99	2.45	12.54	c/

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a/ Harvey and Hackerott, *op. cit*. (1970).
b/ Ward et al., *op. cit*. (1970).
c/ Cate et al., *op. cit*. (1973).

Efficacy Against Sorghum Midge Infestation

Tests by American Cyanamid in Louisiana in 1972 concluded that malathion gave excellent control of the sorghum midge (Barron, 1974)[2]. Doering and Randolph (1963)[3] also evaluated various insecticides against the midge and found malathion to be effective.

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[1] Harvey, T. L., and H. L Hackerott, "Chemical Control of a Greenbug on Sorghum and Infestation Effects on Yields," *J. Econ. Entomol*., 63: 1536-1539 (1970).

[2] Barron, F. R., Manager, Plant Industry Registrations, American Cyanamid, personal communication, Criteria and Evaluation Division, Environmental Protection Agency (1974).

[3] Doering, G. W., and N. M. Randolph, "Habits and Control of the Sorghum Midge, *Contarinia sorghicola*, on Grain Sorghum," *J. Econ. Entomol*., 56:454-459 (1963).

Cost Effectiveness of Sorghum Midge Control

The above papers were the only ones which compared yields of malathion treated sorghum plots against an untreated check. The results of which these experiments showed yield increases ranging from 445 lb/acre to 890 lb/acre. The price of sorghum averaged $2.25/Cwt in 1972 (*Agricultural Statistics*, 1973) and the cost of malathion was $1.20/lb (Bost, 1974). At these prices and costs, the economic benefits would range from $8.81/acre to $18.83/acre.

These tests are summarized below:

Table 38. MALATHION TREATMENT RESULTS ON SORGHUM MIDGE

Date	Application rate (lb AI/acre)	Yield Increase (lb/acre)	Additional increase ($/acre at $2.25/Cwt)	Application Cost at $1.20 16AI + $1.25/ treatment cost	Economic benefit ($)	Source
1960	1.0	890*	20.03	2.45	17.58	a/
1960	1.0	445+	10.01	2.45	7.56	a/
1972	0.5	638	14.36	1.85	12.51	b/
	1.0	871	19.60	2.45	17.15	b/
	0.5	630	14.18	1.85	12.33	b/
	1.0	617	13.88	2.45	12.43	b/

* Treated when 90% of the heads had emerged from boot.
+ Treated 4 days after 90% of heads had emerged from boot.
a/ Doering and Randolph, *op. cit*. (1963).
b/ Barron, F. R., *op. cit*. (1974).

Soybeans

Ogunlana and Pedigo (1974)[1] reported that the potato leafhopper is one of the most common insects on soybeans in Iowa, Ohio, Minnesota and Missouri. Their tests showed that soybean yields declined up to 25.7 bushels/acre, depending upon the number of leafhoppers per plant and soybean stage. They also report that Iowa farmers use malathion at a rate of 1 lb/acre to control the leafhopper.

The 1972 price of soybeans averaged $3.49/bushel (*Agricultural Statistics*, 1973; costs of malathion were estimated at $1.20/lb (Bost, 1974), application costs are $1.25 per treatment. At a yield increase of 25.7 bushels of beans per acre, the economic benefit would be $87.24/acre.

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[1] Ogunlana, M. O., and L. P. Pedigo, "Economic Injury Levels of the Potato Leafhopper on Soybeans in Iowa," *J. Econ. Entomol*., 67: 29-32 (1974).

Sugar Beets

Peay et al. (1969)[1] evaluated granular and foliar insecticides for control of the sugar beet maggot on sugar beets. In tests conducted in Idaho in 1967, an application of 1.5 lb/acre of malathion resulted in a yield of 26.1 tons of sugar beets per acre, an increase of 3.3 tons over an untreated check.

The average price for sugar beets in 1972 was $16/ton (Agricultural Statistics, 1973); the cost of malathion was $1.20/lb (Bost, 1974). At these prices and costs the economic benefit from the use of malathion would be $49.75/acre.

Forage Crops and Rangeland

Approximately 1 million pounds of malathion were used in 1972 to treat alfalfa, clover, grass, hay, pastures and rangeland. The major crop pests are the alfalfa weevil and the grasshopper. The clover head weevil has also occurred as a pest in East Texas.

Alfalfa - The alfalfa weevil was estimated to have caused a loss of $17,430,000 in the North Central States in 1972 due to a combination of yield losses and costs for applying controls (North Central, 1974)[2]. California in 1972 used 156,517 lb of malathion on alfalfa (California, 1972)[3]. These figures indicate a substantial problem due to the alfalfa weevil.

Only two articles were found concerning malathion and the alfalfa weevil. Goonewardene and Filmer (1971)[4] reported on tests conducted at the New Jersey experimental station in Rutgers, New Jersey in 1959, which indicated a yield decline when comparing malathion treated alfalfa to a control. These results showed a decline in yield ranging from 200% to an increase of 23%. The authors concluded that the differences in yield were not significant.

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[1] Peay, W. E., G. W. Beards, and A. A. Swenson, "Field Evaluations of Soil and Foliar Insecticides for Control of the Sugar Beet Root Maggot," J. Econ. Entomol., 62:1083-1087 (1969).

[2] North Central Branch Insect Loss and Control Estimates Soc. 1972, prepared by ESA North Central Branch Survey Entomologists (March 1974).

[3] California Department of Agriculture, Pesticide Use Report (1972).

[4] Goonewardene, H. F., and R. S. Filmer, "A Technique for Evaluation of Field Control of the Alfalfa Weevil Using a Fixed Population," J. Econ. Entomol., 64:327-328 (1971).

Armbrust et al. (1968)[1] conducted field and laboratory tests in 1967 on insecticides for alfalfa weevil control. In a test at Vincennes, Indiana, a yield increase of 183% was recorded 21 days after application of 1.25 lb/acre of malathion and a 141% increase after 28 days occurred. The authors concluded that malathion was effective in warm weather but performed poorly in wet and cool weather.

The price of hay in 1972 averaged \$31.40/ton and yields averaged 2.15 tons/acre (Agricultural Statistics, 1973). Based on the above data, it can be assumed that the use of malathion ranged from no increase in yield to an increase of 183% or 1.78 tons/acre when 1.25 lb of malathion were applied. The cost of malathion is \$1.20/lb (Bost, 1974); application costs are \$1.25 per treatment. Economic benefits would range from \$2.45 to \$53.14/acre.

Rangeland - Grasshoppers on rangeland are often treated with malathion. Skoog and Cowan (1968)[2] estimated that 1,198,909 acres of grasshopper infested rangeland were sprayed with malathion in 1965. Although no yield information was obtained, the above authors showed that 8 oz/acre of malathion aerially applied to rangeland reduced the grasshopper population by 82.2% to 95.0% depending upon the size of spray and height of the flight.

It has been estimated that the yield of grass from rangeland in South Dakota is 0.6 ton/acre and has a value of \$30/ton (Kantak, 1974)[3]. Losses due to grasshoppers are estimated at 35% of the crop which would be equal to 400 lb/acre or \$6/acre. The cost of malathion at \$1.20/lb (Bost, 1974); application costs are \$1.25 per treatment. With an application of 0.5 lb/acre the resulting economic benefit from using malathion on rangeland would be \$4.15/acre.

Fruits and Nuts

An estimated 950,000 lb of malathion were used to treat fruit crops in 1972. It is used primarily to control aphids, mites, fruits flies, leafhoppers, and fruitworms.

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[1] Armbrust, E. J., M. C. Wilson, and T. R. Hintz, "Chemical Control of the Alfalfa Weevil in Illinois and Indiana. I. Comparison of Registered and Experimental Materials," J. Econ. Entomol., 61:1050-1954 (1968).

[2] Skoog, F. E., and E. T. Cowan, "Flight Height, Droplet Size and Moisture Influence on Grasshopper Control Achieved with Malathion Applied Aerially at ULV," J. Econ. Entomol., 61:1000-1003 (1968).

[3] Kantak, B. H., Extension Entomologist, Cooperative Extension Service, Brookings, South Dakota, "Summary of Tests," personal communication (1974).

Cherries - Zwick et al. (1970)[1] evaluated the use of ultra-low volume (ULV) malathion aerial sprays to control the cherry fruit fly in The Dalles, Oregon, in 1969. Two different tests showed that infestation rates varied from 0 to 0.57% when malathion was applied. Comparably untreated fields had infestations varying from 0 to 10.6%. These are summarized in the following table:

Table 39. MALATHION ULV AERIAL APPLICATIONS FOR CHERRY FRUIT FLY CONTROL (THE DALLES, OREGON, 1969, CHERRIES HARVESTED 18 JULY)

Amount applied (oz/acre)	Dates applied	No. cherries examined	% infested
8	5/21, 28; 6/2, 12, 25; 7/4, 13	4,813	0.04
0	Control[a]	2,031	3.15
8	5/21, 28; 6/2, 12, 26; 7/4, 13	2,294	0.09
0	Control[a]	2,006	1.60
8	5/21, 28; 6/2, 12, 26; 7/4, 13	3,607	0.00
0	Control[a]	2,643	0.00

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[a] Recommended fruit fly applications made by growers until 22 to 25 June.

Table 40. MALATHION ULV AERIAL APPLICATIONS FOR CHERRY FRUIT FLY CONTROL (EUGENE, OREGON, 1969)

Amount applied (oz/acre)	No. applications	Date harvested (July)	No. cherries examined	% infested
8	5	8	1,515	0.00
16	5	8	1,643	0.00
0	Control	8	1,306	0.54
8	5	17	1,752	0.57
16	5	17	1,105	0.00
0	Control	17	865	10.06

Since this reference did not give any indication of cherry yield per acre, economic benefits from the use of malathion could not be developed.

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[1] Zwick, R. W., S. C. Jones, F. W. Peifer, R. W. Every, R. L. Smith and J. R. Thiemes, "Malathion ULV Applications for Cherry Fruit Fly Control," J. Econ. Entomol., 65:1693-1695 (1970).

Strawberries - Schaefers (1972)[1] evaluated malathion for control of the tarnished plant bug on strawberries and concluded that application of malathion at 1.0 lb/acre 14 days after application of dimethoate would be an effective program for control of this insect. These results are summarized in Table 42.

Table 41. CONTROL OF THE TARNISHED PLANT BUG ON STRAWBERRIES WITH MALATHION

Pesticide and test	Lb/acre	Applications	No. berries	Percent injury	Percent increase over untreated
(1) Malathion	1.0	2	11,547	24	57
Untreated	--	--	11,981	81	--
(2) Malathion	1.0	3	3,061	14	54
Malathion	1.0	2	3,391	31	37
Malathion	1.0	3	1,767	49	19
Untreated	--	--	2,200	68	--
(4) Malathion	1.0	2	8,619	25	30
Malathion	1.0	3	8,594	26	29
Malathion	1.0	1	8,938	48	7
Untreated	--	--	8,652	55	--
(5) Malathion	1.0	1	2,314	33	38
Malathion	--	--	2,132	71	--

The prices received for strawberries in 1972 averaged $24/cwt and yields averaged 105 cwt/acre (Agricultural Statistics, 1973). The yield increases from the above tests ranged from 6.3% to 38%. At a revenue of $2,520/acre, the additional income at the above yield increases would range from $158.76 to $806.40/acre. Subtracting the malathion cost of $1.20/lb the economic benefit from its use would vary between $156.56 and $805.20/acre.

Vegetables

Approximately 600,000 lb of malathion were used in 1972 to treat insects on a broad variety of vegetables. It is primarily used to control aphids, leafhoppers, beetles and mites on crops such as beans, lettuce, potatoes, cucumbers and melons.

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[1] Schaefers, G. A., "Insecticidal Evaluations for Reductions of Tarnished Plant Bug Injury in Strawberries," J. Econ. Entomol., 65:1156-1160 (1972).

A limited amount of yield data were developed from the literature.

Beans - One study compared the yield of beans when treated with malathion to an untreated test plot for control of the Mexican bean bettle. Smith and Corley (1972)[1] found that the yield of snap beans when treated with six applications of malathion at a rate of 2.0 lb/acre was 5,710 lb/acre. An untreated check plot yielded 2,552 lb and had feeding injury to 100% of the plants.

Snap beans in 1972 averaged 14.5¢/lb (Agricultural Statistics, 1973). This yield increase of 3,158 lb/acre at 14.5¢/lb of beans would result in additional revenues of $457.87/acre. Subtracting the cost of malathion at $1.20/lb (Bost, 1974) would result in an economic benefit of $443.47/acre when malathion was used to control the bean beetle.

Livestock

Malathion was used at a rate of 700,000 lb in 1972 to control a wide variety of insects on livestock and poultry. It is primarily used to control the horn fly on cattle but is also used on stable flies, face flies, mosquitoes, chiggers, lice, ticks, mites and fleas.

The horn fly is one of the most damaging cattle pests especially in southern areas. Most ranchers consider chemical control of this pest good management. Application is most often by the use of insecticide treated backrubbers or by aerial application of ULV sprays. Kinzer (1970)[2] found that ground applications of ULV malathion at a rate of 0.38 oz/animal provided 83% control after 2 days and 59% after 7 days. Dobson and Sanders (1965)[3] concluded that aerial applications of 8 oz ULV malathion provided satisfactory horn fly control in Indiana for 1 week after treatment.

Balsbaugh et al. (1970)[4] found that malathion gave the best control of horn flies after the second day but was poorest at the end of 1 week **when compared to four other pesticides.**

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[1] Smith, F. F., and C. Corley, "Mexican Bean Beetle, Yields and Residues of Malathion Sprays on Snap Beans," J. Econ. Entomol., 65:288-289 (1972).

[2] Kinzer, H. G., "Ground Applications of Ultra-Low-Volume Malathion and Fenthion for Horn Fly Control in New Mexico," J. Econ. Entomol., 63: 736-739 (1970).

[3] Dobson, R. C., and D. P. Sanders, "Low-Volume-High Concentration Spraying for Hornfly and Face Fly Control on Beef Cattle," J. Econ. Entomol., 58:379 (1965).

[4] Balsbaugh, E. U., Jr., G. A. Alleman, B. H. Kantack, and W. L. Berndt, "Aerial Application of ULV Organic Phosphate Insecticides for Controlling Livestock Insect Pests," J. Econ. Entomol., 63:548-551 (1970).

Eschle and Miller (1968)[1] concluded that ULV applications of malathion to dairy cattle daily were effective in controlling the horn fly at a cost of 0.064¢/animal/day. Kinzer (1969)[2] estimated a cost of 61¢/animal for aerial application of malathion and would require an application about once a week to be effective.

Kantak et al. (1967)[3] estimated the seasonal cost of ULV malathion aerial spray would vary from $1.50 to $3.66/year.

The horn fly has been reported to cause a weight loss in cattle. Laake (1946)[4] reported that cattle protected from heavy populations of horn flies have shown a gain of 30 to 70 lb/animal more than untreated cattle.

The price of cattle in 1972 averaged $33.50/cwt (Agricultural Statistics, 1973). Assuming an average additional gain of 30 to 70 lb for treated cattle, this would produce an additional income of $10.05 to $23.45/head. Subtracting costs of applying malathion of $1.50 to $3.66/year, the economic benefit would range from $6.39 to $21.95/head for each pound of malathion applied.

Nonagricultural Uses

Approximately 11,400,000 lb of malathion are used by industrial, commercial, institutional and governmental organizations, and by individual consumers. Because of the wide range of uses, economic values of pesticidal use are difficult to determine. Much of the use is in areas that provide aesthetic benefits such as the control of mosquitos and flies or the treatment of ornamentals around the house, industrial or commercial sites. Economic benefits are derived by the home gardener who uses malathion on vegetables and fruits since his increased yield represents a savings over grocery purchases.

The control of mosquitos by governmental or private agencies may be an economic benefit because of the reduction in disease to human beings. However, the limits of this study do not permit the time to explore this area.

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[1] Eschle, J. L., and A. Miller, "Ultra-Low-Volume Application of Insecticides to Cattle for Control of the Horn Fly," J. Econ. Entomol., 61:1617-1621 (1968).

[2] Kinzer, H. G., "Aerial Applications of Ultra-Low-Volume Insecticides to Control the Horn Fly on Unrestrained Range Cattle," J. Econ. Entomol., 62:1515-1516 (1969).

[3] Kantak, B. H., W. L. Berndt, and E. U. Balsbaugh, Jr., "Horn Fly and Face Fly Control of Range Cattle with Ultra-Low-Volume Malathion Sprays," J. Econ. Entomol., 60:1766-1767 (1967).

[4] Laake, E. W., "DDT for the Control of the Horn Fly in Kansas," J. Econ. Entomol., 39:65-68 (1946).

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